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Report 993-5 June 8, 1945

LISTENING THROUGH
AND
JAMMER ALIGNMENT SYSTEMS
Final Report

Bell Telephone Laboratories OEMsr-993

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION OF RADIO COORDINATION (15)

Project Nos.

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By: E. R. TAYLOR

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LISTENING THROUGH AND JAMMER ALIGNMENT SYSTEMS

Final Report

1. INTRODUCTION

This project is a study of problems of listening through in radio countermeasures and of aligning spot jammers on victim frequencies. The technique gained during NDRC Projects C-27 and C-36 was expanded in this project. Some of the results were checked by use in the development of Radio Sets AN/ARQ-9 and SCR-596-T2 which were direct Army projects but no models were prepared for delivery under this project.

An important part of the work was consultation and advice on numerous other NDRC and Service projects involving radio frequency scanning in connection with either communication searching or countermeasures.

Earlier reports, as noted below, have dealt with automatic frequency alignment and multiple spot jamming. Work on problems of less general interest is covered only in letters and memoranda listed under correspondence. This report consists largely of a discussion of the problems investigated and the results obtained with broad-band and narrow-band scanning receivers. Some of the circuits considered or used are discussed in detail because they may be of interest in the design of future scanning receivers.

2. SUMMARY

This is the final report on Project RP-122 which consisted of research and consultation on problems of listening through in radio countermeasures and of aligning spot jammers on victim frequencies. Earlier reports and memoranda which dealt with automatic frequency alignment, multiple spot jamming and specialized scanning proposals are listed.

Brief reference is made to general problems involved in listening or looking through and jammer frequency alignment and to future work on them.

Detailed consideration is given to broad-band and narrow-band scanning problems as typified by the design and performance of the 18 to 80-mc scanning receiver in AN/ARQ-9 and the 1.85 to 18.5-mc narrow-band receiver in SCR-596-T2. This includes:

1. Design objectives and choice of receiving circuits.
2. Choice of heterodyne oscillator and intermediate frequencies to minimize spurious responses.

3. Signal levels and gain distribution vs. noise and spurious responses.

4. Filter characteristics.

5. Synchronizing of a mechanical scanning oscillator with an electronic jam-scan cycle and narrow-band scan.

6. Typical circuit diagrams.

7. Performance under abnormally severe conditions as indicative of design improvements to be considered if greater scanning-band widths or signal level ranges are desired in future applications of scanning to countermeasures or communications searching.

3. REPORTS ISSUED SEPARATELY

Report 993-1 "Automatic Tuning in Jamming Equipment" dated August 13, 1943 was prepared by Mr. H. M. Straube. It briefly discusses the theoretical aspects of several methods for automatically aligning a "jamming" signal with a "victim" signal. Electronic rather than mechanical tuning is contemplated.

Report 993-2 "Preliminary Design of Airborne Multiple Spot Jamming System" dated August 23, 1944, describes a system such that one to four AN/ARQ-9 radio transmitters could be operated simultaneously in the same airplane in order to jam a like number of communication channels. Both narrow and broadband monitoring facilities are included. Synchronous control of all transmitters and of the frequency scanners is provided as an aid to the observation of victim signals. An operational plan for this system was worked out jointly with Project RP-150 and discussed in Report 966-27.

4. GENERAL PROBLEMS

The broad choice of methods of listening or looking through and of aligning jammer and victim frequencies constitutes the biggest problem in the design of a spot jamming system. It is contingent on many factors such as the frequency range to be covered, types of communication to be jammed and probable enemy tactics in avoiding jamming. It largely determines the efficiency of jamming and ease of operation as well as the size and complexity of the equipment.

After the choice of broad methods, numerous more detailed problems arise such as: mechanical versus electronic control of the jam-scan cycle, interlocking of transmitter and receiver tuning, mechanical versus electronic antenna switching and blocking of transmitting and receiving circuits, and types of aural and visual indication for the operator.

The majority of the problems mentioned above are beyond the scope of this report both because of their complexity and because the majority of the work on them in this laboratory, was carried on under direct Army contracts. The remainder of this report is confined to broad-band scanning used in finding or following a victim signal and narrow-band scanning used in matching jammer and victim frequencies.

5. BROAD-BAND SCANNER

The broad-band scanner discussed herein is the one used in AN/ARQ-9. The band scanned may be 18 to 53 mc or 45 to 80 mc together or individually or an eight-mc band located anywhere in the 18 to 80-mc band. The primary purpose of the broad-band scanner is to indicate the presence and approximate frequency of any signal in the scanned band. When desired, a signal indicative of the frequency to which the associated narrow-band receiver or jammer is tuned may be scanned together with the signals received from the antenna. This facilitates rapid tuning of the jammer to the victim frequency without determining the actual frequency of either.

During the jamming intervals of the jam-scan cycle the antenna is disconnected from the broad-band scanner, the receiving sensitivity is reduced and the jammer frequency indication is produced by a low-energy connection to the jammer. During the "look through" intervals of the cycle the antenna is connected to both narrow and wide-band receiving equipment in a manner which prevents interaction as the narrow-band receiver is tuned. Indications from the broad-band scanner and from the scanner in the narrow-band receiver appear alternately on separate traces on a cathode-ray tube. The scanning repetition rate and the cathode-ray tube persistence are such that each indication appears to be nearly continuous as long as the scanned signal is present.

The following subdivisions of Section 5 discuss some of the broad-band scanner problems and the circuits that were used.

5.1 Single Vs. Triple Superheterodyne Circuit

The basic requirements included ability to scan the entire 18 to 80-mc band or alternately an eight-mc band located anywhere in the 18 to 80-mc band. The change-over from one scanning band to another should be simple and quickly made.

The resolution obtainable should be as good as practicable, especially when the scanning band width is reduced to 8 mc. Level differences between signals in the scanned band as great as 60 db are expected because jammers located in adjacent planes may be transmitting while the broad-band scanner is "looking through."

Consideration was given to a conventional type of receiving circuit with gang tuned r.f. stages and heterodyne oscillator. It was not attractive for the following reasons:

a) Tracking over a 5:1 frequency band of the r.f. stages and an oscillator offset in frequency enough for reasonable image suppression is difficult to design or maintain. b) The tuning complications necessary to change the gang tuned circuits from broad scan (18 to 80 mc) to narrow scan (8 mc) anywhere in the band, would be prohibitive, and c) The simultaneous use of the antenna for a gang tuned broad-band scanner and the narrow-band receiver would require isolation by buffer stages or attenuation, which would lose most of the theoretical advantages of gang tuned preselection.

The use of a superheterodyne circuit without radio frequency gang tuning requires an intermediate frequency located above the receiving band if the scanning band ratio is greater than 1.5 to 1 and if images and spurious responses resulting from intermodulation products of twice signal and twice carrier frequencies are to be avoided. Scanning filter characteristics suitable for the desired resolution are not realizable with practicable structures at frequencies above the 18 to 80-mc band so an additional heterodyne step is necessary to reduce the frequency from the first intermediate frequency to one suitable for the scanning filter.

A third heterodyne step was added for expediency in filter design and stable amplification.

5.2 Choice of Intermediate Frequencies

Multiple heterodyne scanning receivers are subject to all of the difficulties of conventional superheterodyne receivers in addition to others which result from wide-band radio frequency selectivity. Low and high-pass filters may be used to restrict the input frequencies to the desired scanning band but gang tuned radio frequency selectivity is often impracticable as noted above.

The major difficulties result from intermodulation of the various signal and heterodyne oscillator frequencies or from intermodulation of oscillator frequencies alone. Unless the oscillator and intermediate frequencies are carefully chosen the intermodulation products will result in spurious

responses and the operator will see signal indications at frequencies where no radio signal exists. The magnitude of these spurious responses is contingent on such factors as: magnitudes of signal and oscillator voltages, amplifier and modulator distortion characteristics, realizable filter suppression outside the pass band, etc. The number of probable spurious responses increases rapidly as the ratio of maximum to minimum frequencies in the scanned band increases and as the maximum received signal strength exceeds the sensitivity of the receiver.

In general the number of probable spurious responses decreases as the first intermediate frequency is raised. However, desirable filter, oscillator and amplifier characteristics become increasingly hard to obtain as the frequency is raised so it is usually desirable to choose a compromise best adapted to the operational requirements of the particular receiver.

Some spurious responses are unaffected by the choice of intermediate frequencies. For example, if the scanned band ratio is greater than two to one, strong signals at the low-frequency end may appear as signals of twice their frequency as well as in their normal position. In a similar manner bands greater than 3:1 permit thirds, those greater than 4:1 fourths, etc.

The following subdivisions (5.21 and 5.22) review various inequalities which are helpful in the preliminary choice of intermediate frequencies. They are not all inclusive and they are based on ideal filters, i.e. infinite cutoff at the edges of the pass band. After a preliminary choice of frequencies using these inequalities to avoid modulation products which may be expected to cause trouble, practicable filter and modulator characteristics may be studied at the specific frequencies. The tentative frequency choices may then be shifted up or down to obtain the performance desired for the particular application.

5.21 First Modulator Distortion Products

Fig. 1-A (ES-809440) shows the input filter, 1st modulator, 1st intermediate frequency filter and 1st heterodyne oscillator with the following frequency notations:

Range of Input Signal Frequency	$S \pm \Delta C$
Range of 1st Oscillator Frequency	$C_1 \pm \Delta C$
1st Intermediate Frequency	$C_1 - S$

Throughout these discussions capital letters will be used for specific frequencies and small letters for any frequency in the particular band. For example, S represents the center frequency of the R.F. input band and s any frequency in that band.

The following inequalities obtain:

a) Direct transmission at the I.F. is avoided if $C_1 > 2S+\Delta C$

b) $2c_1-s$ products are avoided if $C_1 > 3\Delta C$

c) $2c_1-2s$ products are avoided if $C_1 > S+4\Delta C$

d) $2c_1-3s$ products are avoided if $C_1 > 2S+5\Delta C$

e) $3c_1-2s$ products are avoided if $C_1 > \frac{S+5\Delta C}{2}$

f) $3c_1-3s$ products are avoided if $C_1 > S+3\Delta C$

g) $3c_1-4s$ products are avoided if $C_1 > \frac{3S+7\Delta C}{2}$

h) $2c_1-4s$ products are avoided if $C_1 > 3S+6\Delta C$

Note: The possibility of spurious responses occurring when $ns = C_1-S$ and n = a low integer should be investigated and c_1-2s, c_1-3s etc. products cannot be avoided by choice of intermediate frequency if a 2:1, 3:1 etc. band is to be scanned.

5.22 <u>1st and 2nd Heterodyne Oscillator Intermodulation Products</u>

The first and second heterodyne oscillators may intermodulate to cause spurious responses even if extremely good shielding and filtering is used. Two locations of the second oscillator are of interest i.e., above or below the 1st intermediate frequency.

5.221 <u>2nd Oscillator Below the 1st I.F.</u>

The circuit diagram and nomenclature is shown in Fig. 1-B (ES-809440). The nomenclature is the same as that of Fig. 1-A with the following additions:

2nd Oscillator Frequency $= C_2$

2nd Intermediate Frequency $= C_1-C_2-S$

Pertinent inequalities in this case may be summarized as follows:

If $2c_1 \pm 2C_2$ and lower order products are to be avoided.

a) $C_1 > 3S+2\Delta C$

b) $C_2 < C_1-S$ but $> \frac{C_1+S+2\Delta C}{2}$

c) 1st I.F. $>$ $2S+2\Delta C$

d) 2nd I.F. may range from 0 to $C_2-2S-2\Delta C$

e) Adding 2X to C_1 permits adding X to 2d I.F.

f) For a 2nd I.F. of Y, $C_1 > 3S+2\Delta C+2Y$

If $3c_1 \pm 3C_2$ and lower order products are to be avoided.

a) $C_1 > 4S+3\Delta C$

b) $C_2 < C_1-S$ but $> \frac{2C_1+S+3\Delta C}{3}$

c) 1st I.F. $>$ $3S+3\Delta C$

d) 2nd I.F. may range from 0 to $2C_2-C_1-2S-3\Delta C$

e) Adding 3X to C_1, permits adding X to 2nd I.F.

f) For a 2nd I.F. of Y, $C_1 > 4S+3\Delta C+3Y$

5.222 2nd Oscillator Above the 1st I.F.

Fig. 1-C (ES-809440) shows the circuit diagram. The nomenclature is the same as that of Fig. 1-B except that the 2nd Intermediate Frequency is C_2-C_1+S.

The pertinent inequalities are as follows:

If $2c_1 \pm 2C_2$ and lower order products are to be avoided.

a) $C_1 > 2S+3\Delta C$

b) $C_2 < \frac{2C_1-S-\Delta C}{2}$ but $> \frac{C_1+S+2\Delta C}{2}$

c) 1st I.F. $>$ $S+3\Delta C$

d) 2nd I.F. may range from $\frac{3S-C_1+2\Delta C}{2}$ to $\frac{S-\Delta C}{2}$

e) Adding 2X to C_1, permits 2nd I.F. to be lowered by X.

f) For a 2nd I.F. of Y, $C_1 > 3S+2\Delta C-2Y$.

If $3c_1 \pm 3C_2$ and lower order products are to be avoided.

a) $C_1 > \frac{5S+9\Delta C}{2}$

b) $C_2 < \frac{2C_1-S-\Delta C}{2}$ but $> \frac{2C_1+S+3\Delta C}{3}$

c) 1st I.F. $> \frac{5S+9\Delta C}{2}$

d) 2nd I.F. may range from $\frac{4S-C_1+3\Delta C}{3}$ to $\frac{S-\Delta C}{2}$

e) Adding 3X to C_1, permits 2nd I.F. to be lowered by X.

f) For a 2nd I.F. of Y, $C_1 > 4S+3\Delta C-3Y$.

5.23 Modulation Products Involving the 3rd Heterodyne Oscillator

The most likely spurious responses involving the third heterodyne oscillator are due to oscillator frequency harmonics falling into the scanned radio frequency band. In most cases reasonable shielding and power supply filtering will prevent these responses from being objectionable and they need not be a limiting factor in the choice of the third oscillator frequency.

5.24 Comparison of Optional Frequency Selections

The general procedure outlined above was combined with realizable filter considerations to produce several tentative frequency allocations which were then compared for probable freedom from spurious responses, calibration stability, ease of maintenance, size, power drain, etc. Several of the more interesting proposals are discussed briefly below.

Fig. 2-A (ES-809441) is a block diagram of a receiver designed to avoid $3c_1 \pm 3C_2$ and lower order products. Coaxial type tuning was contemplated for the 1st and 2nd heterodyne oscillators, and the 1st I.F. filter and amplifier. Two rotating condensers were placed in the scanning oscillator coaxial. Both were to be rotated when the full 17 to 81-mc band was scanned. When smaller bands were desired one condenser would be rotated and the other used for frequency centering. As noted on Fig. 2-A the probable spurious responses were only the scanning oscillator minus signal harmonic products but the oscillator frequencies were high tending toward instability of calibration and high maintenance. The coaxial structures were somewhat bulky.

Fig. 2-B (ES-809441) is similar to Fig. 2-A except that the frequencies are lowered about 40%. The probable spurious responses are similar except for $3c_1-3C_2$ appearing as 55 mc. The lower frequencies are better adapted to lumped circuit elements, stability and compactness.

The receiver in Fig. 2-C (ES-809441) was modeled after an existing Army receiver. It represents about the lowest frequency technique which could be used. Other advantages are that the swing of the scanning oscillator is reduced from 64 to 36 mc and the band width of the R.F. amplifiers is almost halved permitting more amplification and improved signal-to-noise ratios. Disadvantages include: many probable spurious responses as noted in Fig. 2-C and signal frequency ambiguity because responses from the upper half of the scanned frequency band are superposed on those from the lower half. The operator may resolve this ambiguity by disabling one of the R.F. inputs and noting if the signal response disappears. This should be a minor handicap because the main use for the receiver will be 8-mc scanning. The input bands include an 8-mc overlap so that any 8-mc band may be scanned without switching.

Fig. 2-D (ES-809441) shows the arrangement finally chosen and built. It includes the best features of the receivers shown on Figs. 2-B and 2-C. The design requirements outlined in sections 5.21, 5.221 and 5.222 were combined to place the two 1st I.F.'s above and below the second heterodyne oscillator frequency. As shown on Fig. 2-D the number of probable spurious responses is less than those of any of the other proposals discussed herein. The frequencies are low enough for reasonable stability and compact design is feasible.

The spurious responses listed in Fig. 2 (ES-809441) were restricted to the low-order products as being the most probable and to simplify comparison of the different proposals. Many higher-order products occur and may be objectionable under certain conditions. Fig. 3 (ES-809442) shows combinations of the 1st and 2nd heterodyne oscillator frequencies up to the fifteenth order. The abscissae are frequencies of the scanning oscillator (c_1) and also the indicated frequency of a response occurring when c_1 is at the corresponding frequency. The heavy horizontal lines represent intermediate frequencies and the sloping lines oscillator combination products. The intersection of a sloping line with an I.F. line indicates that a spurious response may occur when the scanning oscillator is at the frequency corresponding to the intersection. The indicated frequency of the spurious response may be read on the proper abscissa scale. For example, the $3c_1$-$3C_2$ line intersects the 169-mc low band 1st I.F. line at scanning oscillator frequency 211.3 mc indicating a low-band spurious response at 42.3 mc. Of course, the majority of the spurious responses indicated on Fig. 3 (ES-809442) may be avoided by the use of suitable shielding, oscillator levels and modulator characteristics.

5.3 Radio Frequency Circuits

Fig. 4 (ES-809423) is a simplified block diagram of the broad-band scanner that was built. It is more detailed than Fig. 2-D which was discussed in the preceding section and will be referred to in the following discussions of the actual circuit arrangements. It shows nominal voltages at various parts of the circuit in order to indicate the division of gain between the R.F. and I.F. circuits when full sensitivity is used. This is of interest in connection with the suppression of spurious responses as well as in preventing singing tendencies.

The incoming signal from the 50-ohm antenna is divided into two paths by a pad in order to lessen interaction between the input of the narrow band receiver and that of the broad-band scanner. The input impedance of the former is due to a tuned circuit and varies widely as the narrow-band receiver is tuned. If the two receivers were multipled without the pad the varying impedance would cause large fluctuations in broad-band scanner sensitivity. The maximum loss to the narrow band receiver is about 10 db and that to the broad-band scanner is about 4 db.

5.31 Input Filter

The input filter divides the signals in the 18 to 80-megacycle band into two separate branches. One of these branches transmits signals in the 18 to 53-mc frequency range and the other transmits signals in the 45 to 80-mc range. The discrimination characteristics of the two branches are shown on Fig. 5 (ES-809424).

The input filter serves not only to divide the input energy but also to reduce the chances of strong signals outside the desired bands causing spurious responses or other interference. If strong signals below the desired band were allowed to reach the grids of the amplifier tubes or of the modulator, harmonics of these signals would appear within the desired frequency band and produce false indications on the cathode-ray tube screen. Accordingly, relatively high attenuation is provided in the input filter on the low-frequency side of each of the channels. In addition, some attenuation is provided in the input filter for signals above the desired bands in order to prevent false indications produced by difference frequencies which might be caused by the intermodulation of two signals and also to prevent signals above the band from overloading the amplifier tubes and causing undesirable fluctuation of the sensitivity to the desired signals. Attenuation above the band also prevents received signals at the 1st intermediate frequencies from reaching the modulators and causing interference.

The input filter includes two band pass filters with nominal pass bands of 17 to 53 mc and 45 to 81 mc respectively. The overlapping of the two bands between 45 and 53 mc causes design difficulties but is essential to satisfactory band coverage. High and low-frequency dividing networks are used between the inputs of the two band pass filters in order to provide isolation between them in the overlap region. This prevents the large ripples in the pass band transmission characteristics which would occur if the filters were tied together directly. The impedance transformation in each branch is sufficient to provide an insertion gain of about 10 db between a 50-ohm source at the filter input and the grids of the amplifier tubes which are connected to the outputs of the two band pass filters.

The last series arm inductance coil and the terminating resistance of each of the two band pass filters are mounted external to the filter case in order to reduce lead inductances. Blocking condensers are incorporated in the filter output to allow d-c grid bias control of the first R.F. tubes.

A special low-pass equalizing section was built into the filter to absorb energy in the region below 17 megacycles and to assure attenuation in that region where the antenna may be highly reactive and of opposite sign to the filter input reactance.

5.32 R.F. Amplifiers

Two R.F. amplifiers are required as indicated on Fig. 4. One amplifies the 18 to 53 mc or so-called low band and the other the 45 to 80 mc so-called high band. Each amplifier contains two stages using 6AK5 tubes. The coupling networks between tubes and between the second tube and the modulator are low-pass filters in the low band amplifier and band pass filters in the high band amplifier. Manual adjustment of the d-c bias on the tube grids is provided for R.F. sensitivity control. This bias is automatically changed to a high negative value during the transmitting intervals of the jam-scan cycle in order to prevent overloading.

The nominal gain from the antenna to the first modulator is 19 db for the low band and 25 db for the high band. The sensitivity control range and the amount of R.F. blocking obtained at full sensitivity, varies from about 80 db at the lower frequencies to 60 db at the higher frequencies. Special shielding and component location are used so that transmission in the minimum sensitivity or blocked condition is largely confined to that through the grid-plate capacitance of the tubes.

The R.F. discrimination characteristic from antenna to 1st modulator is shown on Fig. 6 (ES-809425) for the low band and Fig. 7 (ES-809426) for the high band. Two curves are shown on each figure in order to illustrate the effect of the increase of vacuum tube input capacitance which occurs at small values of negative grid bias. This is of negligible importance except as it changes the cutoff at the high frequency end of each band.

Another 6AK5 tube (not shown on Fig. 4) is included in each R.F. amplifier to afford a controllable input for the part of the transmitted signal that is used to give a jamming frequency indication as mentioned in the first part of Section 5. The grids at these tubes are connected to a 50-ohm coaxial cable which extends to a high ratio potential divider in the transmitter. The plate of one tube is connected to the plate of the second tube in the low band amplifier. The other tube is similarly connected to the high band amplifier. The sensitivity control provided for these tubes is similar to that of the main R.F. amplifiers except that automatic blocking during the jam-scan cycle is not required.

5.4 Scanning Heterodyne Oscillator

As shown on Fig. 4 the scanning oscillator operates from 186 to 222 mc and supplies heterodyning power to each of the 1st modulators at a level that is high relative to the modulator signal inputs in order to minimize spurious responses due to signal harmonics or intermodulation products. A motor driven capacitor sweeps the frequency over either the entire 186 to 222-mc band or any 8-mc part of it. Synchronizing and phasing pulses are produced to control the multivibrator in the associated narrow-band scanner and hence to insure that the broad-band scanner display on the cathode-ray tube occurs at proper time intervals. Detailed discussion of the oscillator, its coupling to the modulators, the motor and the synchronizing arrangements are given in the following subdivisions.

5.41 The Oscillator Circuit and Tuning Capacitor

A balanced push-pull circuit is used as indicated on Fig. 8. The tank circuit inductance is a U-shaped copper wire. Both it and the capacitor plates are silver plated. The tuning capacitor consists of two parallel oblong stator plates and two pairs of ungrounded semicircular rotor plates. This arrangement requires no sliding contacts and simplifies the selection of optional scanning band widths and location, as follows: The pair of rotor plates at one end of the stator plates is motor driven at 960 RPM so that 1/2 of a capacitor cycle occurs during a "look through" interval of the jam-scan cycle (approximately 1/32 of a second). Only the decreasing half of the capacitor cycle is used because the cathode-ray tube displays narrow band indications during the other half.

The motor-driven rotor may be shifted axially by a two-position toggle action external control. This affords optional spacing between stator and rotor plates of approximately 0.02 and 0.09 inch. The wide spacing is used when a nominal 8-mc scanning band width is desired. The close spacing is used when the full 36-mc band is desired.

The pair of rotor plates at the other end of the stator plates is manually rotated to provide whatever additional capacitance is necessary to locate the scanning band as desired. The associated dial is calibrated in megacycles representing the highest frequency scanned when it is in the corresponding angular position and the motor-driven plates are widely spaced. Of course, this dial must be set to a predetermined position when the motor-driven plates are closely spaced to provide the maximum scanning band width.

The stator plates and the rotors are mounted on ceramic plates in order to minimize losses. The materials of the rotor shafts and supporting framework have different expansion coefficients, chosen to minimize variations in plate spacing over a temperature range of -50° to +85°C. Counterbalances are provided to reduce the dynamic unbalance caused by the semicircular rotor plates. "Oilite" bearings are used on the motor-driven rotor and split brass bearings are used on the manual rotor. Brass adjustable end thrust bearings operating against steel inserts in the counterbalances facilitate adjustment of the spacings between capacitor plates. Insulating shafts connect the rotors to their respective drive mechanisms. This serves a two-fold purpose in preserving the balance of the push-pull oscillator circuit and avoiding cross-talk paths which might be caused by conducting shafts passing through the shield which encloses the oscillator circuit.

The 6J6 oscillator tube is symmetrically located with regard to the stator plates and is as close to their edges as is possible with reasonable maintenance accessibility. Originally the centers of the stator plates were scalloped between the areas which oppose the rotors, in an attempt to shorten the leads to the tube socket and still leave clearance for maintenance. The scalloping was abandoned after it was found to cause low level spurious oscillations which beat with the primary oscillations and caused spurious responses at the scanner output.

Both pairs of rotor plates are semicircular. This produces approximately linear capacitance change versus angular rotation over most of the range and is of advantage in covering the numerous scanning band locations and widths. The resultant nonlinearity of frequency change versus angular rotation is not objectionable because of the low ratios of maximum to minimum total capacitance in the oscillator. The

rate of change distortion which occurs near the capacitance extremes of the motor-driven rotor, is not harmful because it occurs at times when cathode-ray retrace or jam-scan switching occurs and the scanner output is blocked.

5.42 Coupling Between Oscillator and Modulators

The grid of one modulator is coupled through a small capacitance to one of the oscillator stator plates. The other modulator is similarly coupled to the other plate in order to preserve oscillator symmetry and reduce lead lengths. This coupling arrangement shunts the R.F. input to the 6AK5 modulator tube but causes negligible reduction in sensitivity because the small capacitance represents a large impedance to the relatively low radio frequencies.

The outputs of the R.F. coupling networks which supply the R.F. to the modulators, represent capacitance at the oscillator frequencies. This capacitance and that of the coupling capacitor constitute a potential divider which reduces the oscillator voltage to the desired value for the modulator. The lead lengths are short to minimize inductance and make the divider nearly pure capacitance and hence of constant ratio throughout the oscillator frequency band.

The major effect of the coupling arrangement on the oscillator circuit is to increase the fixed capacitance across the tank circuit. The major effect on the R.F. networks is to increase the capacitance shunting the modulator input. Allowance was made for this increase of capacitance in the design of the R.F. networks.

5.43 Driving Motor

A .75 H.P., 28-volt, series wound motor is used to drive the rotor of the oscillator capacitor which controls the frequency changes effecting the desired scanning. The power capacity is rather large in order to provide a large factor of safety and stable operation over the temperature range of -50° to +85°C. The motor is equipped with a Lee type centrifugal speed regulator and internal gearing to provide a shaft speed of 960 RPM. The armature speed is 6000 RPM.

The average shaft speed is held well within design limits of 935 to 985 RPM. However, short period speed fluctuations such as those occurring during a single shaft revolution, are large enough to be noticeable. They result in a sidewise movement of signal indications on the cathode-ray tube, which

amounts to as much as 1/16 inch at times. This is due to a momentary change in motor speed relative to that of the horizontal sweep on the tube. The horizontal sweep is produced by an electronic multivibrator because the tube is alternately used for narrow-band electronic scanning. The multivibrator is synchronized with the rotating condenser just prior to each scan, as discussed in the next section, but it, of course, cannot follow momentary speed changes occurring during a scan. The momentary speed fluctuation is minimized by RC contact protection and by reducing the resistance which is shunted by the regulator contacts to as small a value as is consistent with the expected range of motor line voltage and load.

The motor shaft is connected to the capacitor rotor through 1:1 gears to simplify mechanical layout and to facilitate the axial movement of the rotor which is required in changing the width of the scanning frequency band. Highly flexible ring type couplings are used to insulate the oscillator from motor vibration.

5.44 Synchronizing Arrangements

A previously mentioned, the same jam-scan cycle and cathode-ray tube are used for the narrow-band receiver and the broad-band scanner. Therefore, their scanning cycles must be synchronized. The jam-scan cycle and the narrow-band scan are governed by an electronic multivibrator which is much easier to control than the motor in the broad-band scanner. Accordingly, the multivibrator is placed under the control of the motor.

Two types of synchronizing are required. The first insures that the electronic sweep starts when the scanning capacitor is in a predetermined angular position. The other insures that the "look through" interval of the jam-scan cycle occurs when the scanning capacitor is decreasing capacitance and hence the scanning oscillator frequency is increasing. For the purposes of this discussion the first type will be called synchronizing because it is effective whenever the motor is running, and the other will be called phasing because it is effective only when the jam-scan cycle is out-of-phase with the capacitor. Normally phasing is required only when the motor is started.

Both synchronizing and phasing originate in pulses produced by small inductor type alternators in which a small soft iron slug embedded in the periphery of a nonmagnetic disc is caused to pass between magnetized pole-pieces. These alternators are geared to the rotor of the scanning capacitor in such a manner that the "sync" alternator rotates twice as

fast as the capacitor rotor but the "phase" alternator rotates at the same speed as the capacitor rotor. The mechanical arrangement is indicated on Fig. 9-A (ES-809437). The actual physical arrangement of the pole-pieces differs from that of the figure in that the slug passes between the pole-pieces which are parallel to the axis of the nonmagnetic disc.

When the slug of the "sync" alternator passes its pole-pieces a single sharp alternation is produced. The alternation passes to the grid of a tube which is biased near cut-off so that only a sharp negative pulse is passed on. This negative pulse causes the multivibrator to retrace and start a new cycle. The free running rate of the multivibrator is approximately 26 cps and approximately 32 "sync" pulses are produced each second. Accordingly, the "sync" pulses terminate each multivibrator cycle and maintain a predetermined relationship between the angular position of the capacitor and the start of the horizontal sweep on the cathode-ray tube.

If the slug of the "phase" alternator passes its pole-pieces at the wrong time such as during a look through interval, it produces a pulse intermediate in time between "sync" pulses. This extra pulse terminates the multivibrator sweep and starts a new one. Effectively the multivibrator makes two cycles instead of the usual single cycle, during a one-half turn of the scanning capacitor. This enables the jam-scan cycle to catch up with the motor and insures that the next look through will occur at the right time, because when the "phase" alternator passes its pole-pieces at the proper time the resulting alternation is suppressed without sending an additional pulse to advance the multivibrator.

Figures 9-B and 9-C indicate the circuit arrangement and show typical wave forms starting at a time when a "sync" pulse occurs but the phasing is incorrect. The 1st "sync" pulse is amplified and passes over the SYNC LEAD to the multivibrator as shown on Fig. 9-B. This initiates the sawtooth retrace as shown by the line slanting upward in the lower part of Fig. 9-C. The cathode-ray tube is blanked during the retrace time. As soon as the retrace is completed and the sawtooth line starts downward, the blanking is removed. With the assumed improper phasing this occurs while the scanning capacitor is increasing capacity as shown at the top of Fig. 9-C. This results in the start of an improper BBS display. In the meantime the slug of the "phase" alternator is approaching its pole-pieces. As soon as it gets there it passes an alternation to the cathode follower which passes on a positive pulse. This pulse passes through the "sync" alternator winding to the amplifier and causes the multivibrator to retrace again. This not only terminates the improper display but also advances the electronic

commutator just as a normal retrace does. This switches the cathode-ray tube to the narrow-band scanner (its proper position) until the next "sync" pulse occurs. From then on everything is normal with BBS and NBS displays in the proper sequence. The next time the "phase" slug passes its pole-pieces the BBS DET BIK wave form shown at the bottom of Fig. 9-B, will be sufficiently negative to hold the cathode follower cut off during the "phase" pulse and no additional pulse will be passed on to the multivibrator.

5.5 <u>1st Intermediate Frequency Amplifiers</u>

General 1st I.F. amplifier objectives included the following:

a) Enough gain to raise the minimum desired signal at least 10 db above 2nd modulator noise.

b) Enough pass band width to permit normal field variations in succeeding oscillator frequency and I.F. tuning such as those caused by shifting grid bias to adjust I.F. gain, without more than a db change in sensitivity.

c) Sufficient attenuation at scanning oscillator and 2nd heterodyne oscillator frequencies and at their harmonics to prevent the former getting into the second modulator or the latter getting into the 1st modulator with enough amplitude to cause spurious responses. Sixty db was thought to be adequate.

d) Reasonably narrow pass band width to limit the number of received signals simultaneously present in the I.F. amplifier tubes and hence sensitivity variations due to overloading. This is hard to evaluate but might be a factor when operating in close proximity to several strong transmitters.

A single stage I.F. amplifier could be built to meet these objectives if the frequencies were low but three stages are used in the actual amplifiers which operate at 141 mc and 169 mc. This increase in the number of stages is due to the following:

a) The input, output and grid-to-plate capacities of the vacuum tubes constitute low impedances at these frequencies and the tube input admittance is high. These factors prevent the use of high impedance filters and high selectivity per stage.

b) The low grid-plate reactance lowers the attenuation obtainable from plate-to-grid and several stages are required to obtain the attenuation in the "backward" direction which is necessary to prevent spurious responses due to the second oscillator frequency or its harmonics reaching the first modulator.

Single tuned coupling circuits are used between the 1st modulator and the first amplifier tube, between amplifier tubes and between the third amplifier tube and the 2nd modulator. The plate of a buffer amplifier tube passing the 155 mc 2nd oscillator frequency is multipled to the plate of the third amplifier tube so the final coupling circuit passes not only the I.F. but also the 2nd oscillator frequency which is 14 mc removed from the I.F. 6AK5 tubes are used because of their small capacitances. The effective Q of the first three coupling circuits of each amplifier is 40 but that of the last coupling circuit was reduced to 30 because it passes both I.F. and 155 mc.

Each tuned circuit except the last is coupled to the following grid through a small capacitor. This capacitor and the vacuum tube grid-cathode capacity form a 4:1 potential divider with the following results:

a) The vacuum tube admittance is reduced 16:1 in its effect on the Q of the tuned circuit.

b) The effect on the tuned circuit of the vacuum tube input capacitance and its variations is correspondingly reduced.

c) The stage gain is not reduced 4:1 because the higher effective Q constitutes a higher load impedance for the preceding pentode.

Fig. 10 (ES-809427) shows the discrimination characteristic of the entire 169-mc amplifier. Fig. 11 (ES-809428) is a similar characteristic of the 141-mc amplifier.

About 40-db gain may be obtained with either I.F. amplifier with average tubes at minimum grid bias. Theoretical singing margins are 15 db or better and no tendency toward singing has been observed. The nominal working gain is about 20 db and the remaining 20 odd db constitutes a reserve for use when other tubes have subnormal gain. Gain control is obtained by varying the grid bias on the last two stages. The plate and screen supply for the first two stages is brought to a switch so that the undesired I.F. may be disabled when the full 18 to 80-mc scanning band is not required.

b) The low grid-plate reactance lowers the attenuation obtainable from plate-to-grid and several stages are required to obtain the attenuation in the "backward" direction which is necessary to prevent spurious responses due to the second oscillator frequency or its harmonics reaching the first modulator.

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Some tests were made using a double tuned inductively coupled interstage in order to reduce the number of stages. The band-pass characteristic was unsatisfactory due to stray capacity couplings interacting with the inductive coupling. Promising results were obtained with carefully shielded primary and secondary coils coupled by a very small capacitor. This was not pursued further because the single tuned coupling arrangement could be produced much quicker and appeared to require less maintenance.

5.6 2nd Heterodyne Oscillator

The 155 mc or 2nd heterodyne oscillator should be insensitive to temperatures of -50° to +85°C, power supply variations and vibration, in order to preserve the frequency calibration of the scanner. It should also be such that tube changes, maintenance activity, etc. cannot alter its frequency by more than a fraction of a megacycle because accurate frequency meters may not be available for field maintenance. Otherwise, if the scanner calibration is off, it will be difficult to determine whether the trouble is in the first or second heterodyne oscillator. Furthermore, if the 2nd oscillator frequency departs materially from 155 mc, sensitivity will be reduced because the scanned signal will not be centered in the 1st I.F. amplifiers. This is likely to result in the maintenance man retuning the 1st I.F. and obtaining a still more abnormal circuit lineup.

Two types of oscillators were considered. The frequency determining element of the one that was chosen is a coaxial cavity. The other used a crystal. These circuits are discussed in the following subdivisions.

5.61 155-Mc Coaxial Cavity Oscillator

Fig. 12 is a schematic of the oscillator used in the scanner. It shows a conventional tuned-plate tuned-grid circuit with the exception that the main frequency determining unit is a cylindrical coaxial cavity. The cavity symbol on the figure is indicative of a cross section through the axis of the cylinder. The cylinder is roughly 2-1/2 inches long and 2-1/2 inches in diameter.

Electrically, the coaxial cavity may be considered as a very short transmission line with the outer end short-circuited and the near end loaded with capacitance to provide a high impedance, high Q circuit resonant at the desired operating frequency.

Actually the line is so short relative to one wave length that lumped values of inductance and capacitance may be used for computation with no practical error. The inductance

may then be considered to be that of the center post and the capacitance to be that between the inner and outer shells including the trimmer.

The shells, end plates, trimmer and post are made of a special alloy known by the trade name "Free Cutting Invar 36." This alloy was chosen because of its low temperature coefficient of linear expansion and because the parts could be machined without difficulty. A low coefficient of expansion is desirable in obtaining a high degree of frequency stability over a wide temperature range because the resonant frequency, and hence the frequency of the oscillator is dependent upon the physical dimensions of the cavity. All conducting surfaces are silver plated in order to increase the Q of the cavity.

The frequency adjusting trimmer consists of a disc recessed in the end plate. This disc is held in place by a threaded stud which screws through the end plate and is secured by a locknut and Glyptal cement after factory adjustment. The connection to the grid of the tube is brought into the cylinder through a glass bead type insulator. It is tapped into the center post about midway. This is a relatively low impedance point and hence lessens the effect of external changes.

After assembly, the cap is soldered in place and tested for air leaks at all points except around the trimmer adjusting screw. Air is applied through a hole in the base of the outer shell. This hole is then capped by a screw and a phenol fibre washer. After the trimmer has been adjusted to resonate the cavity at the proper frequency, the air hole screw and trimmer screw are thoroughly sealed with Glyptal cement. This precaution against air leaks is taken to prevent moisture from entering the cavity and condensing or forming rime upon the surfaces. This would change the Q and the loading capacitance and thereby, change the frequency of the oscillator.

Temperature-frequency tests were made on oscillators using brass as well as invar cavities. The improvement due to the invar was about 10:1 as was to be expected from the coefficients of linear expansion. The most striking improvement occurs when the ambient temperature changes rapidly. This causes transient conditions until the heat is again uniformly distributed throughout the cavity. For example, a ± 40°C change in temperature resulted in ± 30-kc frequency change after the temperature of the invar cavity reached equilibrium but deviations of 100 kc occurred while the temperature was changing rapidly.

Another effect was noted during the temperature runs. After the temperature was raised to a high value and then returned to and held at the initial value, the frequency differed from its initial value. This appeared to be caused by stress relieving during the heat cycle so the production cavities were raised to temperatures well above the operating range and then cooled slowly. This reduced the hysteresis effect to negligible proportions for subsequent temperature changes in the operating range.

5.62 155-Mc Crystal Oscillator

Crystal control of the 155-mc oscillator would be desirable not only for its inherent frequency stability but also because it permits the entire oscillator circuit to be made compact and lightweight. However, fundamental crystal operation at 155 mc is not feasible and the usual technique of using a low-frequency crystal oscillator followed by several stages of frequency multiplication would greatly increase the number of probable spurious responses. The crystal frequency and that of each multiplier stage could be expected to combine with the scanning oscillator frequency to cause intermodulation products falling into one of the I.F. bands.

A technique whereby the crystal operates as a transducer to restrict the oscillator feedback to odd multiples of the crystal fundamental frequency, was developed and a crude model built. The performance was promising but a special crystal mounting and electrode arrangement was required. Other crystal developments were more urgent at the time so the new crystal circuit could not be put into production in time for use in the scanner.

Fig. 13 (ES-809439) illustrates the contemplated crystal operation. Fig. 13-A indicates the mechanical distortion occurring in the crystal when it is driven at its fundamental frequency. Fig. 13-B indicates the distortion when the drive frequency is three times the fundamental frequency. The effect is roughly similar to splitting the original crystal longitudinally into three identical layers each 1/3 the thickness of the original and cementing them together. Each operates at three times the original frequency. The same type of operation would be observed if the drive frequency were any odd multiple of the fundamental but not if it were an even multiple. In that case the outer surfaces would be trying to move in same direction and hence opposing the electric drive.

Fig. 13-C shows the crystal arranged as a transducer. The driving voltage is applied to a pair of electrodes at one end of the crystal and the output voltage is taken from another pair at the other end. If a suitable shield is inserted between the pairs of electrodes the only coupling

between them will be that due to the mechanical motion of the crystal. The crystal thus becomes a transducer capable of passing only the crystal fundamental frequency and its odd harminics.

Fig. 14 (ES-809436) shows the circuit of an oscillator using such a transducer at its 31st harmonic. It is a balanced tuned-grid tuned-plate oscillator with the transducer in the feedback circuit. Other feedback paths are reduced by careful shielding between grid and plate circuits. The experimental transducer was housed in a hermetically sealed holder consisting of two glass cups with their edges fused to a metal disc which constituted the shield between the two pairs of crystal electrodes. This disc was inserted in a hole in the shield between the oscillator grid and plate circuits.

The particular crystal odd harmonic at which the oscillations occur is determined by the grid and plate tuning. The frequency stability of these circuits must be good enough to prevent shifts to other odd harmonics, under any operating condition. If this is done, the oscillator frequency stability in per cent of the operating frequency should be as good as that of an oscillator operating at the fundamental of the crystal.

5.63 Coupling Between Oscillator and Modulators

The 2nd heterodyne oscillator frequency (155 mc) is only about 10 per cent removed from the two first intermediate frequencies (141 and 169 mc) so isolation is required to prevent interaction and excessive loading of the oscillator circuit. 6AK5 pentodes are used as buffer amplifiers. The grids are coupled to the oscillator plate circuit through capaictors small enough to constitute negligible oscillator loading. The 6AK5 mutual conductance is high enough to supply adequate modulator voltage with the small input and without grid overloading and consequent excessive harmonic distortion.

As noted in Section 5.5, the coupling between each buffer tube and the associated modulator is obtained by multipling the buffer plate with the plate of the I.F. amplifier tube immediately preceding the modulator. Both of these tubes are pentodes so the net effect is to increase the unavoidable capacitance across the tuned circuit which couples them both to the modulator. Neither the signal nor the heterodyne frequency circuit is seriously shunted by the other.

5.7 Low-Frequency Circuits

The outputs of the two 6AK5 2nd modulators are multipled and connected to the tuned primary of a 14-mc network which lowers the impedance to 50 ohms for ease in testing and connection via a coaxial cable to the low-frequency circuits which are assembled on a "plug-in" chassis.

5.71 2nd Intermediate Frequency Amplifier

A single tuned network is used to couple the 50-ohm 14-mc input to the grid of a 9003 tube constituting the single stage 2nd I.F. amplifier. A double tuned network couples the amplifier to the 3rd modulator.

The 14-mc discrimination charateristic is shown on Fig. 15 (ES-809429). This discrimination was adequate to suppress the usual image and low order modulation products but did not prevent some very high-frequency coupling between the high and low-frequency assemblies which caused noticeable spurious responses on one model. The frequencies at which the coupling occurred were not identified but the trouble was cured by bridging a 10 micro-microfarad capacitor across each end of the 50-ohm coaxial cable. This, of course, did not affect the 14 mc characteristic.

The nominal gain from 2nd modulator plate to the 3rd modulator grid is 10 db but a gain control range of about ± 6 db from that, is provided by an adjustable resistance in the cathode circuit of the 9003 tube. This is a lineup adjustment to care for variations in amplifier or 3rd modulator tubes.

5.72 3rd Modulator and 13.545-Mc Crystal Oscillator

The third modulator is a 6SA7 pentagrid converter operating in a conventional circuit with a separate 13.545-mc oscillator. The bias voltage for the signal grid is controlled by a front panel "High-Low" switch to afford a sensitivity reduction of 20 db when full sensitivity is not desired. Sensitivity reduction at this point is often preferable to R.F. sensitivity reduction because it does not reduce the attenuation caused by the R.F. block during the jam-scan cycle. It is also useful in avoiding spurious responses which may increase in magnitude as the vacuum tubes age.

The third heterodyne oscillator is controlled by a 13.545-mc crystal. A 6J6 tube is used in a conventional circuit.

5.73 Scanning Filter and 3rd I.F. Amplifier

The scanning resolution obtainable with this broad-band scanner is determined not only by the characteristics of the scanning filter and associated I.F. amplifier but also by the length of cathode-ray tube trace used for signal display. The available trace length is approximately 4 inches. Accordingly, when the 18 to 53 mc or 45 to 80-mc band is scanned the pips corresponding to two signals separated by 50 kc would be within .005 inch of one another. Similarly, when an 8-mc band is scanned signals 25 kc apart would result in pips less than .01 inch apart. This indicates that the scanning filter need be only moderately good to afford resolution as good as is usable with a four-inch trace.

The scanning filter band width should approximate the optimum for the scanning speed as it is a controlling factor in the realizable signal-to-noise ratio. The rate of rise of scanning filter cutoff attenuation and the phase characteristics also require attention because relative signal strengths as great as 60 db are expected and poor filter characteristics would result in excessively wide pips when high level signals are scanned.

Fig. 16 (ES-809430) shows the discrimination characteristics of the scanning filter and the 455-kc amplifier both separately and together. The scanning filter is made up of coil and condenser elements in two ladder type sections, a confluent type and a six-element peak section. The I.F. amplifier selectivity is obtained from three single tuned interstage coupling networks. The pass band width of the three I.F. stages is appreciably wider than that of the scanning filter so that the filter attenuation and phase characteristics predominate at frequencies within or near the pass band.

The 455-kc amplifier utilizes one 9003 and two 6AK5 tubes. The nominal maximum gain through the scanning filter and the amplifier is 80 db. An adjustable resistor in the cathode circuit of the 9003 tube is provided for maintenance adjustments to the normal 73-db value.

5.74 Detector-Limiter

One-half of a 6SN7 double triode is used as a detector in deriving the video pulses from the 455-kc signals. The 455-kc amplifier output is connected across plate and cathode. The grid is used as a blocking control. For example, when the narrow band scanner is being used, and the broad-band display is not desired, the automatic control circuits apply a highly

negative voltage to the grid of the detector and about 40 db blocking is obtained. This is sufficient to suppress the broad-band display even when signals 60-db stronger than just visible are being received, because the amplifier tube immediately preceding the detector over-loads to limit the detector input to values less than 40 db above visibility.

The remaining half of the 6SN7 double triode is used to amplify the detector output and to limit the height of the pulses applied to the vertical deflection plates of the cathode-ray tube so that the maximum pip height is 3/4 inch. Fig. 17 (ES-809432) shows the limiting characteristic of the I.F. amplifier, detector and limiter. As the input increases above that for a just visible pip (approximately .05 volt) the pip height rises more rapidly than the input until it reaches .9 of its maximum value. Further increase in input results in small increase in pip height until the maximum pip height occurs at about 25 db above visibility.

5.8 Miscellaneous

5.81 Signal Levels

The broad-band scanner differs radically from a communication receiver in the signal levels and overloading to be encountered in the various amplifier and modulator stages. Automatic volume control or manual sensitivity adjustment is used in most communication receivers to hold the signal levels within a narrow range at all except the low level input stages. This is not feasible in a broad-band scanner which indicates stations ranging in level from just visible to 60 db higher, during a single scan. Overloading must occur somewhere when a strong signal is received.

If the overloading occurs in a broad-band stage two or more signals may be present simultaneously and the gain reduction caused by the overloading may result in the weaker signal being lost. This condition could be improved by concentrating the majority of the gain in the stages having the narrowest pass band i.e. after the scanning filter. If this is carried to excess other troubles are encountered such as the following: a) Poor signal-to-noise ratios because weak signals will be comparable to modulator noise. b) Spurious responses due to oscillator intermodulation products being comparable to weak signals and c) Final I.F. amplifier singing due to the concentration of gain at a single frequency.

Overloading which occurs only during the short time that the strong signal is in the scanning filter does little harm if the time constants of the overloaded circuits are small enough for full sensitivity to be recovered before the next weak signal is scanned.

The nominal signal voltage values indicated on Fig. 4 show the gain distribution chosen for the broad-band scanner. It may be summarized roughly as follows:

Part of Circuit	App. Band Width	Gain-db
Radio Frequency	38 mc	20-25
1st Modulator	38 mc	0
1st Intermediate Frequency	2 mc	15-20
2nd Modulator	2 mc	9
2nd Intermediate Frequency	200 kc	10
3rd Modulator	200 kc	8
3rd Intermediate Frequency	25 kc	73
Total antenna to detector		140

At full sensitivity this results in the modulator noise being negligible and the ability to handle a signal 60 db stronger than that required for a 3/4 inch pip, with negligible overloading in the stages preceding the 3rd modulator i.e. the weak station would need to be within about 100 kc of the strong one for masking due to overload to be a factor. The resolving power for 60-db level differences is 150 kc or greater so the level distribution appears to be reasonable from noise and overload standpoints. As noted later in Section 5.84 there is some indication that the distribution is also about right from spurious response considerations.

The 41-mc sensitivity was measured as a one-half volt signal (approximately 120 db above visibility) was tuned across the band from 28 to 52 mc. The sensitivity reduction caused by this excessive signal ranged from 10 to 25 db. A similar run was made with the interfering signal reduced by 14 db to .1 volt. In that case the sensitivity reduction varied from 0 to 10 db.

5.82 Sensitivity

The signal sensitivity of the broad-band scanner varies with the scanning speed and hence with the width of the frequency band being scanned. When the full 18 to 53 mc or 45 to 80-mc band is being scanned the sensitivity is about 6 db less than it is when a nominal 8-mc band is scanned.

This results from using a scanning filter band width which favors the signal-to-noise ratio and scanning resolution obtainable during the 8-mc scan.

The response caused by vacuum tube or resistance noise, however, is substantially unaffected by changes in scanning speed. Accordingly, the signal-to-noise ratio obtainable during an 18 to 53 mc or a 45 to 80-mc scan is about 6 db poorer than that during an 8-mc scan. The signal-to-noise ratio obtainable when responses from both the 18 to 53 mc and the 45 to 80-mc bands are superposed to cover the entire 18 to 80-mc band in a single scan, is about 3 db further reduced because the noise from both radio frequency inputs is combined.

The minimum useful signal-to-noise ratio is somewhat contingent on operator experience and skill in distinguishing between the grass-like noise fringe along the cathode-ray tube base line and the relatively constant pip corresponding to a signal. The maximum usable sensitivity when the entire band is displayed is about 3 microvolts. It is determined by noise. When small bands are scanned the sensitivity is correspondingly improved.

Noise voltages produced by internal sources such as the d-c motor that drives the capacitor in the scanning oscillator, are effectively suppressed by shielding and by-pass capacitors.

5.83 <u>Resolving Power</u>

The resolving power of a scanner is difficult to define because it depends on the experience of the operator, the relative strength and constancy of the signals, etc. as well as on the purpose of the resolution. If the purpose is to adjust the frequency of one signal as closely as possible to that of another signal of comparable strength, accuracies of a few kc may be had by observing the "beating" of the scanning pip even when the full band is scanned.

Perhaps the type of resolution most useful for searching is the minimum frequency separation between signals which permits the presence of the weaker to be noted. The following table gives the results of tests made with one broad-band scanner under laboratory conditions. It is probably more optimistic than results under field conditions would be.

Relative Signal Strength	Resolving Power in Kc	
	10 Mc Scan	36 Mc Scan
1:1	60	200
10:1	70	250
100:1	100	400
1000:1	150	450

5.84 Spurious Responses

As noted earlier numerous spurious responses are possible and some are unavoidable under extreme conditions. Special precautions were taken as discussed in the sections dealing with particular phases of the development. Other more general precautions included:

a) Extensive filtering of all leads entering shielded compartments. Plate, screen, etc. power leads were brought out close to the associated tube socket. Small disc type "feed through" capacitors were inserted directly in the shield. Care was taken to avoid resonances due to lead length inductances and by-pass capacitors, etc.

b) Relative locations of various components and shields were chosen and experimented with to minimize common ground paths and other less obvious coupling paths.

These precautions involved considerable amounts of development effort but proved to be relatively easy to apply in subsequent production of 100 scanners.

The following results of tests made on one scanner are representative of the performance of production units. The image and 1st I.F. interference rejection measured at maximum sensitivity were as follows:

Broad-band Scanner Band	Interfering Frequency-Mc	Image or I.F. Interference Rejection-db
Low (18 to 53 mc)	355 to 391	>100
High (45 to 80 mc)	327 to 363	>100
Low (18 to 53 mc)	169 ± .025	>100
	84.5 ± .012	>100
	56.333 ± .008	100
	42.25 ± .006	90
	33.8 ± .005	90
	28.167 ± .004	92
	24.143 ± .004	92
	21.125 ± .003	97
High (45 to 80 mc)	141 ± .025	>100
	70.5 ± .012	60
	47 ± .008	80
	35.25 ± .006	90
	28.2 ± .005	97
	23.5 ± .004	98
	20.143 ± .004	99

The only one of these that is close to causing objectionable interference, is the high band one due to a 70.5-mc signal where the rejection is only 60 db. The chances of its occurring are small because the interfering signal not only must be very strong relative to the desired operating sensitivity but also its frequency must be within about 12 kc to 70.5 mc. However, it would be very annoying if it did occur because it would produce interference across the entire high band response unless the radio frequency sensitivity were reduced. This effect is due to distortion in the radio frequency part of the circuit and indicates that the present amount of radio frequency gain is about as large as could be tolerated without reducing the distortion by a radical circuit changes such as the use of balanced push-pull amplifiers and modulators.

Spurious responses due to heterodyne oscillator intermodulation usually were observable during the initial lineup of a broad-band scanner. In most cases these responses could be reduced to invisibility by careful adjustment of oscillator voltages and amplifier gains but they may return as the various tubes age. No particular product was determined to be more likely than others. Apparently the coupling paths occurred at frequencies well above operating frequencies and varied from model to model. The following results are typical measurements before final lineup.

Broad-band Scanner Band	Apparent Frequency of Indication	Equivalent* Strength in Microvolts	Intermodulation Product If In 1st Modulator	If In 2nd Modulator
17-53 mc (Low Band)	21.3	5.6	$6C_2-4c_1$	$5C_2-4c_1$
	28.3	5.0	$4c_1-4C_2$	$4c_1-5C_2$
	42.3	4.4	$3c_1-3C_2$	$3c_1-4C_2$
45-81 mc (High Band)	49.2	5.5	$4c_1-4C_2$	$5C_2-4c_1$
	56.3	7.0	($6C_2-4c_1$) (or) ($7c_1-8C_2$)	$4c_1-5C_2$
	70.3	2.5	$5C_2-3c_1$	$3c_1-4C_2$

*This indicates the strength of a signal at the input of the scanner required to give a pip of the same height and position as the pip due to the spurious response. The scanner was adjusted for maximum gain.

It may be noted that each spurious response due to 1st and 2nd heterodyne oscillator intermodulation has at least two possible sources, one in the first modulator and another in the second modulator. The order of the product differs but the apparent frequency is the same. If the second modulator product is known ($5C_2-4c_1$ for example) a low band first modulator product may be found by the algebraic addition of C_2 ($C_2+5C_2-4c_1=6C_2-4c_1$) and a high band first modulator product may be found by the algebraic subtraction of the second modulator product from C_2 ($C_2-5C_2+4c_1=4c_1-4C_2$). This multiplicity of possible sources makes difficult the location of the coupling or nonlinearity causing the actual response.

The spurious responses listed in the above table appear to be generated in one or both of the second modulators because the low and high-band responses occur at the same scanning oscillator frequencies and with approximately the same magnitudes. In some other models some spurious responses occured only in one band and appeared to be generated in the first modulator.

Available data are not sufficient for rigorous conclusions but the indication is that the radio frequency gain and hence the signal level through the 1st I.F. amplifiers could not be materially reduced without encountering serious spurious responses.

6. NARROW-BAND RECEIVER

Jamming or searching often requires a combination aural and visual receiver of the so-called adapter type. Such a receiver affords close visual monitoring of a narrow-band centered on the frequency that is aurally monitored. Wide tuning ranges and good selectivity against relatively strong signals are often desired.

The usual receiver of this type is a single heterodyne for aural reception and a double heterodyne for visual reception. A part of the received signal is taken from the first intermediate frequency and modulated by a scanning oscillator to produce the narrow-band scan. The radio frequency stages, 1st modulator and the I.F. stages that are common to both aural and visual reception, perform general functions that are the same as those of similar parts of communication receivers but the requirements for them are much more severe. For example, the usual tuned circuit type of radio frequency selectivity causes undesirable attenuation changes across the scanning band. This becomes more objectionable as the receiver is tuned to lower frequencies where the scanning band width is a larger percentage of the tuned frequency. For similar reasons the intermediate frequency pass band should be abnormally wide.

The rate of change of attenuation with frequency at the edges of both the R.F. and I.F. bands should rise more rapidly than is necessary for communication receivers. This is true for the R.F. stages because the wider R.F. and I.F. pass bands result in smaller frequency separation between the desired frequencies and other frequencies which may cause image or other spurious responses. Unless frequencies near the I.F. pass band are sharply attenuated they will combine with the scanning oscillator frequency to form low order intermodulation products which appear as spurious responses.

Design difficulties increase rapidly with the following: a) R.F. tuning range, b) Width of scanning band, and c) Range of input signal strength to be received without spurious responses. These factors are interrelated so that one may be expanded at the expense of others but eventually a point is reached where further expansion results in poor performance or prohibitive circuit complication. Optimum choice of intermediate and heterodyne oscillator frequencies becomes increasingly important as the ranges noted above are widened.

A 1.85 to 18.5 mc narrow-band receiver which was designed for SCR-596-T2 is of interest because wide ranges are covered. It illustrates typical difficulties and means

of meeting them. Accordingly, this receiver and its performance are discussed in the following subdivisions.

6.1 Design Objectives for a 1.85 to 18.5 Mc Receiver

The design objectives may be summarized as follows:

a) Tuning Range - 1.85 to 18.5 mc

b) Sensitivity - 1 microvolt or better

c) Scanning Band Width - 100 kc

d) Input Signal Strength Range without Objectionable Spurious Responses - 40 db

6.2 Choice of 1st Intermediate Frequency

In this discussion the circuit arrangement shown on Fig. 18 (ES-809443) is assumed and the following frequency nomenclature is used:

R_{max} = the maximum frequency to be received

R_{min} = the minimum frequency to be received

r = any radio frequency

a = any frequency in the 1st I.F. band

b = any 1st heterodyne oscillator frequency

c = any scanning oscillator frequency

$2\Delta c$ = the width of the scanned band

A high 1st intermediate frequency is helpful in avoiding responses due to images (r-b) and modulation products from 2b-3r.

A low 1st intermediate frequency facilitates gang tuning of the radio frequency stages and the 1st heterodyne oscillator. It also permits more attenuation to radio signals at the 1st intermediate frequency. If low enough it avoids 2r-b, 3r-2b, etc. modulation products. For example a 1st I.F. lower than one-half of (R_{min} $-3\Delta c$) avoids the 2r-b products and one lower than one-third of (R_{min} $-4\Delta c$) avoids the 3r-2b products.

Nine hundred kc (approximately one-half R_{min}) was chosen for the 1st I.F. It was thought to be a reasonable

compromise between image rejection and gang tuning difficulties. This was substantiated by measurements on the completed receiver. The following spurious responses were noted when the interfering frequency was stronger than that necessary for normal response by the indicated number of db. The receiver was adjusted for full sensitivity and tuned to frequencies such that the interfering frequency was in or near the pass band of the radio frequency. When the receiver was tuned across the band, some products disappeared and others appeared as was to be expected. The following list is not intended to be complete but is thought to be representative of the suppression afforded to products of the modulation orders indicated.

Modulation Product	db Suppression
a (Direct 1st I.F.)	80
r-b (Image)	90 or greater
2r-b	45
2b-2r	100
3r-2b	60
3b-3r	> 120
4r-3b	65
7r-5b	65
8r-6b	80
9r-7b	70
8b-10r	80
9b-11r	70
13r-8b	75
14r-11b	70
13b-16r	75
19r-15b	75
17b-21r	75

This indicates that the design objective of 40 db is met in the present design but that a lower intermediate frequency might be desirable if the ratio of signal strengths to be received without sensitivity adjustment should be increased to 50 db. It also indicates that something more radical than a new choice of intermediate frequency is required if a range much greater than 50 db is required. In that case, circuit changes such as the use of a balanced modulator and reduction of signal and oscillator levels at the first modulator, even at the expense of signal-to-noise ratio, should be considered.

6.3 Choice of 2nd Intermediate Frequency

Improper choice of the 2nd intermediate frequency may result in spurious responses not only in the scanning reception but also in the aural receiver. A tentative choice may be made from the general considerations outlined below. Filter, modulator and oscillator characteristics

practicable at the tentative frequencies may then be studied and new frequencies chosen until a balanced design is obtained.

General considerations include the following:

a) The fundamental and second harmonic of the scanning oscillator should not fall into the 1st intermediate frequency band or into the radio frequency range of the receiver because they are likely to cause audio interference.

b) Harmonics of the scanning oscillator should not fall into the 2nd I.F. band.

c) The 2nd intermediate frequency should be higher than about two and a half times the band width of the preceding I.F. to reduce the probability of two input signals intermodulating to produce the second I.F.

d) The mean frequency of the scanning oscillator should be greater than about five times the scanning band width in order to avoid complicated oscillator design, if electronic tuning is desired.

e) The 2nd I.F. should be such that suitable scanning filter characteristics may be realized with reasonable filter size and circuit complexity.

f) The lower order products of intermodulation of the scanning oscillator frequencies and those passed by the 1st intermediate frequency amplifier, should fall outside the 2nd I.F. pass band. The lowest order permissible is a function of the 2nd modulator characteristics and of the signal strength range to be encountered. Abrupt cutoff at the edges of the necessary 1st I.F. pass band and a narrow scanning band are both helpful in meeting this requirement as they lessen the frequency range of each modulation product.

The frequencies chosen for the actual receiver are:

2nd Intermediate frequency - 375 kc
Scanning Oscillator frequencies - 475 to 575 kc
1st I.F. (as noted in Section 6.2) - 900 kc

The solid horizontal lines of Fig. 19 (ES-808768) show the frequency ranges of the scanning oscillator, desired 1st I.F. signals and their intermodulation products up to the ninth order in the vicinity of the 2nd I.F. Vertical

lines indicate the frequency locations of the 1st and 2nd I.F.'s. The dashed line extensions to the horizontal lines indicate the increased frequency range of the modulation products and hence the greater difficulty in avoiding them if the pass band of the first I.F. is two and a half times as wide as the scanning band. The nomenclature is that used in Section 6.2 - a indicates any frequency in the 1st I.F. pass band and c any scanning oscillator frequency.

Sketchy measurements of the intermodulation suppression in the receiver gave the following indications:

Product	db Suppression
2c-a	$>$ 80
2a-2c	$>$ 80
3c-2a	37
3c-a	80
4c-2a	45
3a-4c	50
5c-3a	35

This indicates that the design objective of 40 db was not met for 3c-2a and 5c-3a products. Different choices of intermediate frequencies could have avoided these products if the scanning band width had been reduced about 50% but this cure appeared to be more undesirable than the spurious responses. These particular spurious responses appear at the edge of the scanning band and rapidly dwindle to disappearance as the receiver is tuned in an attempt to bring them into the aural receiver. This amplitude reduction is due to the sharp cutoff of the 1st I.F. band pass characteristic.

6.4 Radio Frequency Circuits

The major circuit elements of the radio frequency stages, the 1st modulator and the 1st heterodyne oscillator are indicated on schematic Fig. 20 (ES-809444). This figure also shows the nominal voltages occurring when a 4-microvolt signal is received from the antenna because they are of interest in connection with the modulation products discussed in the preceding sections.

Band pass radio frequency selectivity characteristics are obtained by the use of two double tuned interstage networks and a single tuned circuit coupling to the 50-ohm antenna. Coil switching is used to divide the 10:1 - 1.85 to 18.5 mc tuning range into four parts as indicated on the drawing. Band pass characteristics complicate the design of the radio frequency stages not only by increasing the number of variable capacitors to be gang tuned with the oscillator

capacitor but also because the effects of fortuitous coupling between circuit elements become much more pronounced. Abnormally good shielding and grounding are required to prevent the pass band characteristic tilting or peaking at one side or the other as the receiver is tuned across a band.

Fig. 21 (ES-809445) shows the discrimination characteristic of the R.F. stages when tuned to 2 mc. The characteristics at some other tuning frequencies showed peaking or tilting amounting to several db in spite of careful clamping of the removable shield cover and grounding of the coil switch shaft where it passes through the various shields.

A separately excited pentagrid converter is used in a conventional circuit. A.V.C. or manual sensitivity control voltages are applied to the radio frequency stages, the modulator and the first I.F. stage. This same control lead is used to block the receiver during transmitting.

The time constants of this lead require special consideration to insure full recovery of sensitivity by the time the "look through" scan commences.

6.5 Common Intermediate Frequency Circuit

The .9 mc intermediate frequency amplifier that is common to both audible and visual responses is shown on the right-hand side of Fig. 20 (ES-809444). The majority of the selectivity is obtained from a band pass filter between the modulator and 1st I.F. amplifier tube. This filter consists essentially of two double tuned circuits loosely coupled to one another. The .9 mc amplifier discrimination characteristic is shown on Fig. 22 (ES-809446). As noted in earlier sections the attenuation rises rapidly at the edges of the ± 50 kc scanning band.

6.6 Scanning Circuits

The scanning circuits are shown on the upper part of Fig. 23 (ES-809447). The output of the common .9 mc amplifier is brought in through a coaxial cable to a splitting pad which divides the energy between scanning and aural receiving circuits. The scanning part passes through a "step-up" network and a buffer amplifier to the 2nd or scanning modulator. The buffer amplifier serves to reduce interaction between the modulator and the aural receiver and to limit abnormally high signal voltages to values that will not injure the crystal scanning filter which follows the modulator.

The 525 ± 50 kc scanning heterodyne frequency and the 900 ± 50 kc signals are applied in parallel to the control grid of a pentode modulator. The 375 kc second I.F. is selected

by a crystal type scanning filter which has characteristics of the type discussed in an NDRC Project C-36 report dated January 22, 1943. Conventional circuits are used for the remainder of the second I.F. amplification, detection and video presentation.

The horizontal sweep for the cathode-ray tube and the sawtooth control for the scanning oscillator are obtained from a two tube multivibrator. Push-pull reactance tubes are used to frequency modulate the triode oscillator over the range of 475 to 575 cps.

The selectivity of the 375 kc second I.F. is shown on Fig. 24 (ES-809118). In and near the pass band it is largely determined by the scanning filter in order to preserve its special phase and attenuation characteristics.

6.7 Aural Receiving Circuits

The narrow-band 900 kc intermediate amplifier, detector and audio amplifier circuits are shown on the lower part of Fig. 23 (ES-809447). Conventional circuits are used. The I.F. selectivity is shown on Fig. 25 (ES-809117).

6.8 Sensitivity and Noise Performance

The input signal required to produce a one-half inch visual indication varied from .15 to .65 microvolt as the receiver was tuned across the 1.85 to 18.5 mc band. 7 db more input was required to produce a 10-milliwatt audio output, when the input signal was 30% modulated by 400 cps.

The noise response at full sensitivity was too small to be visible on all four receiving bands. The corresponding audio noise response was less than one-half a milliwatt.

This excellent sensitivity and noise performance indicates that a somewhat better balanced design with regard to spurious responses might be had by reducing the radio frequency gain and increasing that of the final intermediate frequency. This would have required more elaborate shielding and by-passing in the 375 kc circuits in order to prevent the greater gain from resulting in poorer scanning resolution. Slight amounts of feedback tend to upset the phase characteristics of the scanning filter and result in materially poorer scanning resolution.

7. FURTHER WORK

Many problems in connection with listening through, jammer alignment and associated narrow and wide band scanning receivers remain to be solved before the relative merits of

different types of systems may be evaluated with ease or their performance in many frequency bands predicted. The importance of obtaining general solutions is contingent on operational requirements and in part may be dependent on common interest with other uses such as communication searching and monitoring. Careful study and reporting of the performance of equipment designed for specific uses and of effects when it is used under abnormally severe conditions will do much to indicate which problems are most pressing.

Some of these problems are listed below without attempting to evaluate their relative importance.

a. Comparison of the merits of broad-band scanners having synchronously swept radio frequency selection, with those having broad-band R.F. selectivity and only the heterodyne oscillator frequency shifted at the scanning rate. This should result in determining the operating conditions which make either markedly superior to the other.

b. Study of frequency converters and methods of coupling to heterodyne oscillators without excessive noise penalty in covering wide frequency ranges and signal level differences with a minimum number of spurious responses.

c. Improved synchronizing of electronic and mechanical scanning.

d. Improved mechanically swept oscillators with reduced retrace time.

e. Electronically controlled FM. oscillators for use at higher frequencies and with larger precentage swing.

f. Means for preventing a jammer in one airplane interfering with a broad-band scanner in an adjacent airplane and operating in the same frequency band.

g. Means for reducing radar interference into scanning receivers.

h. Use of balanced R.F. circuits to reduce reradiation and spurious responses at harmonics of signal frequencies.

8. REFERENCES

8.1 Laboratory Notebooks

The following notebooks include information used in this project and other data on AN/ARQ-9 and SCR-596-T2 Radio Sets.

Engineer	Notebook No.	Items
J. T. Bangert	4157	155 Mc Coaxial Cavity - Design
	4207	155 Mc Coaxial Cavity - Oscillator Tests
	4282	155 Mc Coaxial Cavity - Invar Temperature Tests
	4110) 4234) 4290) 4379) 4524)	18 to 80 Mc Scanner - Scanning Oscillator and I.F. Amplifier Tests
T. L. Dimond	3860) 3975)	(Narrow & Broad-band Scanning - (Synchronizing Schemes
	3964	(Multiple Jamming - (Control Circuits
	3984) 4118) 4256)	(18 to 80 Mc Scanner - (Scanning Oscillator, Synchronizing (& Video - Circuit Design & Tests
H. W. Evans	3768) 3805) 3892) 3939) 4310)	1.85 to 18.5 Mc Receiver - Circuit Design
	4430) 4499) 4570) 4594) 4670) 4734)	1.85 to 18.5 Mc Receiver - Circuit Tests & Performance
J. G. Harden	4128 4217 4344 4533 4615	18 to 80 Mc Scanner - Circuit Design, Tests and Performance

Engineer	Notebook No.	Items
R. E. Johnson	4309) 4429) 4516) 4707)	18 to 80 Mc Scanner - Circuit Tests
J. May	4305) 4468) 4557)	18 to 80 Mc Scanner - Circuit Tests
P. B. Murphy	3507	18 to 80 Mc Scanner - Mechanical Design
E. R. Taylor	3680) 3751)	(1.85 to 18.5 Mc Receiver - (Intermediate Frequency (Considerations
	3824	Broad-band Scanner - Intermediate Frequency Considerations
	4072	18 to 80 Mc Scanner - Design Objectives
	4265	Multiple Jamming - Design Objectives

8.2 Correspondence and Reports

Memorandum by E. I. Green dated 1/8/43 "Panoramic Research Problems."

Memorandum by E. I. Green dated 3/17/43 "Draft Proposal for Research and Consulting Work on Scanning Reception and Allied Problems in the Field of Countermeasures."

Interim Report dated 3/25/43.

Letter J. H. Moore to E. I. Green dated 3/31/43 attaching Contract Information Forms.

Letter E. I. Green to J. H. Moore dated 4/2/43 returning Contract Information Form with breakdown of expense.

Letter of Intent Irvin Stewart to C. R. Smith dated 4/26/43 - Informal authorization to proceed with the project.

Interim Report dated 4/27/43.

Memorandum by E. R. Taylor dated 4/28/43 "Circuit Arrangements for the 2 to 18 Mc Equipment."

Memorandum by E. I. Green dated 5/4/43 "Information given to J. H. Moore re Panoramic Labs."

Memorandum by E. R. Taylor dated 5/7/43 "Scanning Receivers with Push-Button Selection of the Bands Scanned - Case 23264."

Memorandum by E. I. Green dated 5/11/43 "Inspection of Pimpernel."

Memorandum by E. I. Green to H. A. Burgess dated 5/19/43 requesting patent consideration of ERT memorandum dated 5/7/43.

Interim Report dated 5/24/43.

Memorandum by E. R. Taylor dated 6/2/43 "Inspection of RCA Electric Wave Synthesizer."

Letter Irvin Stewart to C. R. Smith dated 6/10/43 - Additional authorization and time extension.

Contract No. OEMsr-993 dated 6/17/43.

Memorandum by E. R. Taylor dated 6/19/43 "Proposal Development by the Panoramic Radio Corporation."

Interim Report dated 6/25/43.

Memorandum by E. I. Green dated 7/15/43 "Visit to RRL and General Radio Company."

Memorandum by E. I. Green dated 7/20/43 "Consultation with RCA Engineers."

Memorandum by E. I. Green dated 7/20/43 "Conference with Panoramic Radio Corporation Representatives."

Interim Report dated 7/22/43.

Letter J. H. Moore to E. I. Green dated 7/22/43, requesting comments on Panoramic Radio Proposal.

Letter E. I. Green to J. H. Moore dated 7/26/43 commenting on Panoramic Radio proposal.

Memorandum by E. R. Taylor dated 7/28/43 "Scanning Receiver Design."

Report 993-1 dated 8/13/43 "Automatic Tuning in Jamming Equipment."

Letter J. H. Moore to E. I. Green dated 8/19/43 - requesting comments on specifications prepared by Commander D. R. Hull.

Interim Report dated 8/25/43.

Memorandum by E. R. Taylor dated 8/26/43 "Monitoring and Tracking Indicators for Communications Jamming."

Letter E. I. Green to J. H. Moore dated 8/26/43 transmitting ERT memorandum dated 8/26/43.

Memorandum by E. R. Taylor dated 8/27/43 "Broad-band Scanning Receivers with Radio Frequency Tuning Varying at the Sweep Rate."

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Letter J. H. Moore to E. I. Green dated 10/5/43 "Data on Enemy CW Transmitters."

Interim Report dated 10/29/43.

Letter J. H. Moore to E. I. Green dated 11/19/43 "Patent No. 488,297."

Interim Report dated 11/22/43.

Memorandum by E. R. Taylor dated 11/27/43 "Conference with Panoramic Radio Corp. Representatives."

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Letter E. I. Green to J. H. Moore dated 11/29/43 "NDRC Project at Panoramic Radio."

Letter E. I. Green to J. H. Moore dated 11/30/43 "Hardy Patent Application Serial No. 488,297.

Interim Report dated 12/18/43.

Letter Irvin Stewart to C. R. Smith dated 12/22/43 extending project to 8/31/44.

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Memorandum by J. H. Moore dated 2/5/44 "Conference on Airborne Spot Jamming Problem."

Memorandum by J. M. West dated 2/7/44 "NDRC Study of Spot Jamming."

Memorandum by M. E. Campbell dated 2/10/44 "Air Cigar."

Letter R. W. Larson to E. I. Green dated 2/29/44 - authorizing work on multiple jamming.

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Memorandum H. A. Burgess to E. I. Green dated 3/16/44 "Scanning Receivers with Push-Button Selection."

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Letter J. H. Moore to E. I. Green dated 3/23/44 - requesting comments on Panoramic Radio Corp. Report #1138-1.

Memorandum by H. M. Straube dated 4/1/44 "Large - Deviation F.M. Oscillators."

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Memorandum by E. R. Taylor dated 4/28/44 "Preliminary Consideration of Multiple Jamming Equipment."

Memorandum by W. H. Tidd dated 4/29/44 "Inspection of AN/ARQ-10 Radio Equipment.

Memorandum by E. R. Taylor dated 5/3/44 "Some Notes on the British Air Cigar."

Letter E. I. Green to M. Wallace dated 5/17/44 transmitting BSTJ reprints.

Interim Report dated 5/23/44.

Memorandum by E. R. Taylor dated 6/5/44 "Description of Multiple Jamming System."

Interim Report dated 6/23/44.

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Interim Report dated 7/26/44.

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Report 993-2 dated 8/23/44 "Preliminary Design of Airborne Multiple Spot Jamming System."

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Interim Report dated 3/23/45.

Memorandum by E. R. Taylor dated 4/9/45 "Search Receivers for PF."

9. LIST OF FIGURES

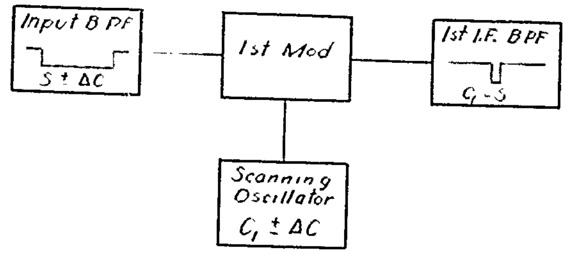

Fig A

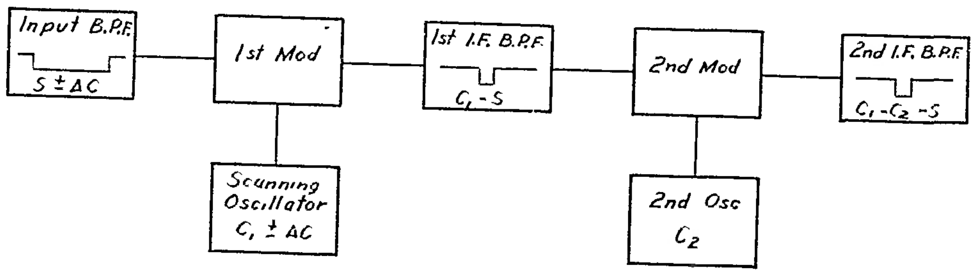

Fig B

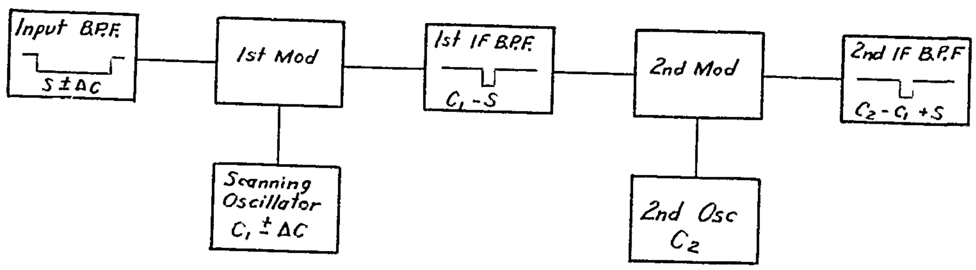

Fig C

FIG 1

SECRET

TITLE

Superhetrodyne Diagrams

SCALE

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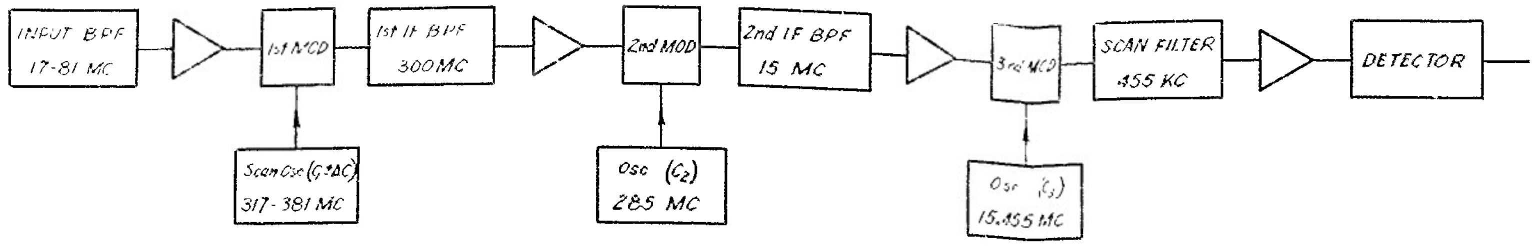

FIG A

17-41 MC	$C_1 - 2S$
17-27	$C_1 - 3S$
17-20	$C_1 - 4S$

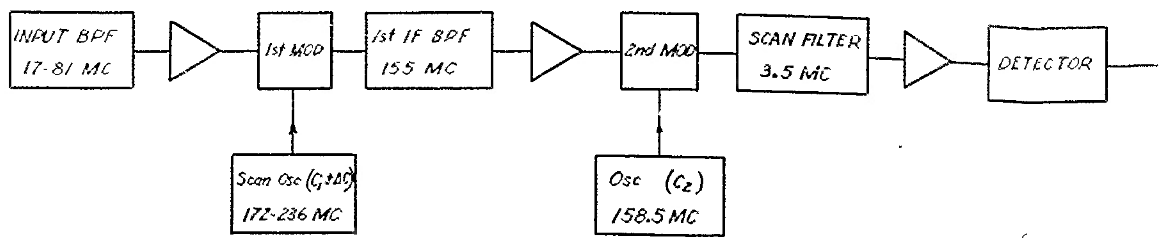

FIG B

55 MC	$3C_1 - 3C_2$
17-41	$C_1 - 2S$
17-27	$C_1 - 3S$
17-20	$C_1 - 4S$

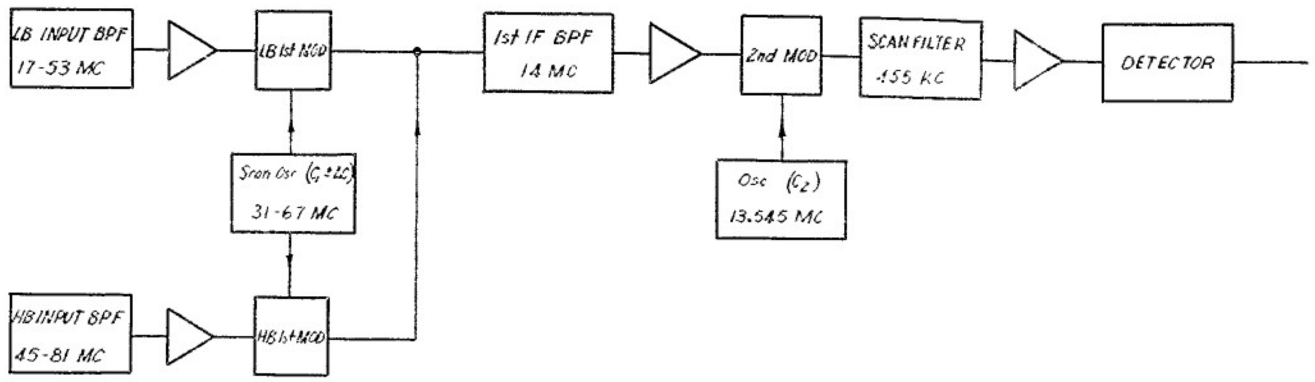

FIG C

26 MC	$3C_2 - C_1$
26	$2C_2 - C_1$
27	$C_1 - 3C_2$
40	$C_1 - 3C_2$
54	$3C_2 - C_1$
54	$2C_2 - C_1$
55	$C_1 - 3C_2$
68	$C_1 - 3C_2$
17-19	$2C_1 - S$
17-46	$2C_1 - 2S$
45-47	$2C_1 - S$
52-81	$2C_1 - 2S$
17-27	$C_1 - 2S$
17-18	$C_1 - 3S$

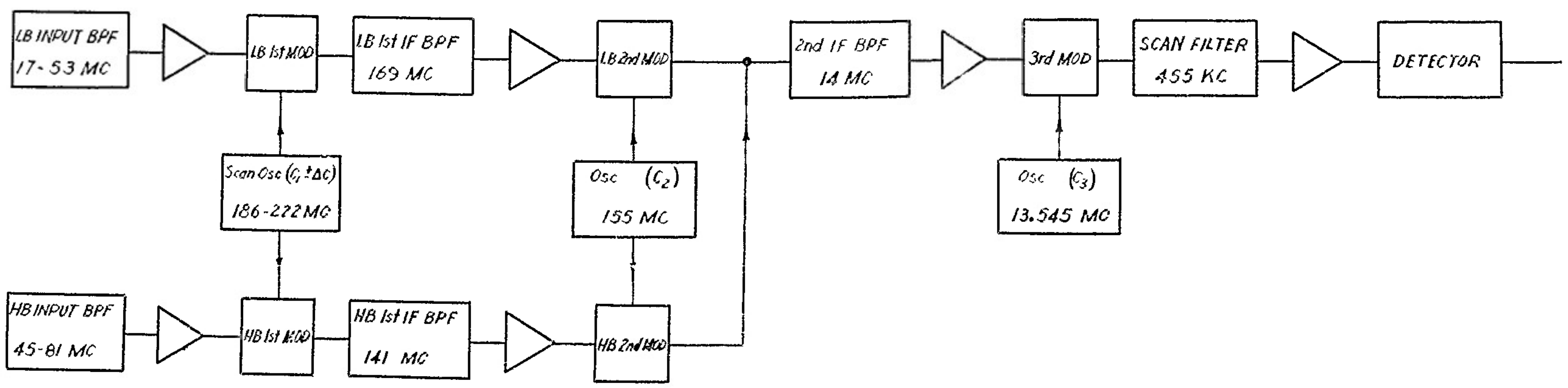

FIG D

42 MC	$3C_1 - 3C_2$
61	$3C_1 - 3C_2$
17-27	$C_1 - 2S$
17-18	$C_1 - 3S$

FIG 2

ISSUE 1 4-14-45

Optional Scanning Receiver Block Diagrams

SCALE
APP'LS ERT
CH
DR REJ

BELL TELEPHONE LABORATORIES, INC
NEW YORK

ES 0-809441

SECRET

STOCK SPECIFICATION

SIZE	KIND	SHAPE	TEMPER

E-1878 A (9-43)

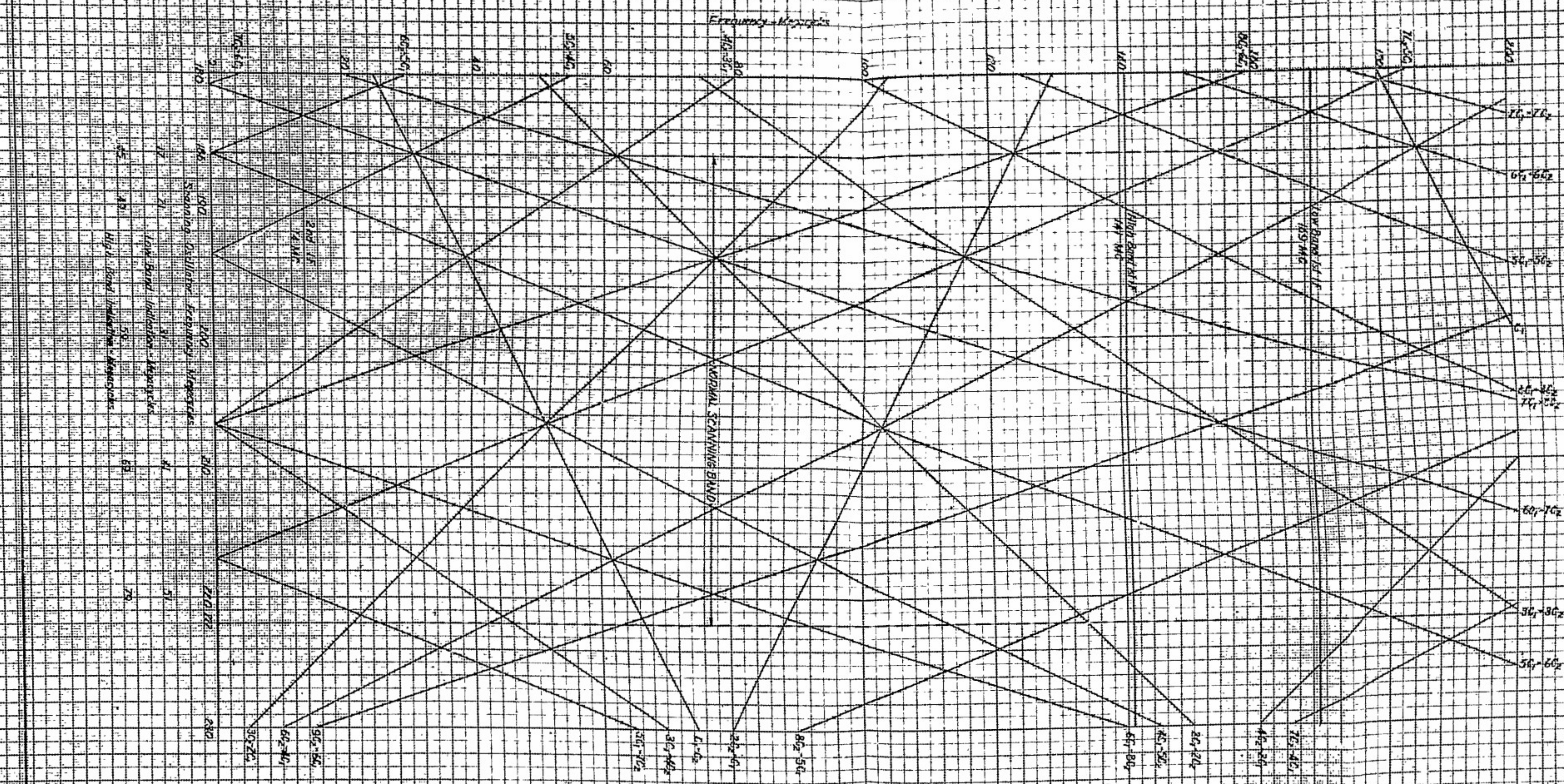

FIG. 3

1st and 2nd Hetrodyne Oscillator Intermodulation Products

ERT

ES-809442

SECRET

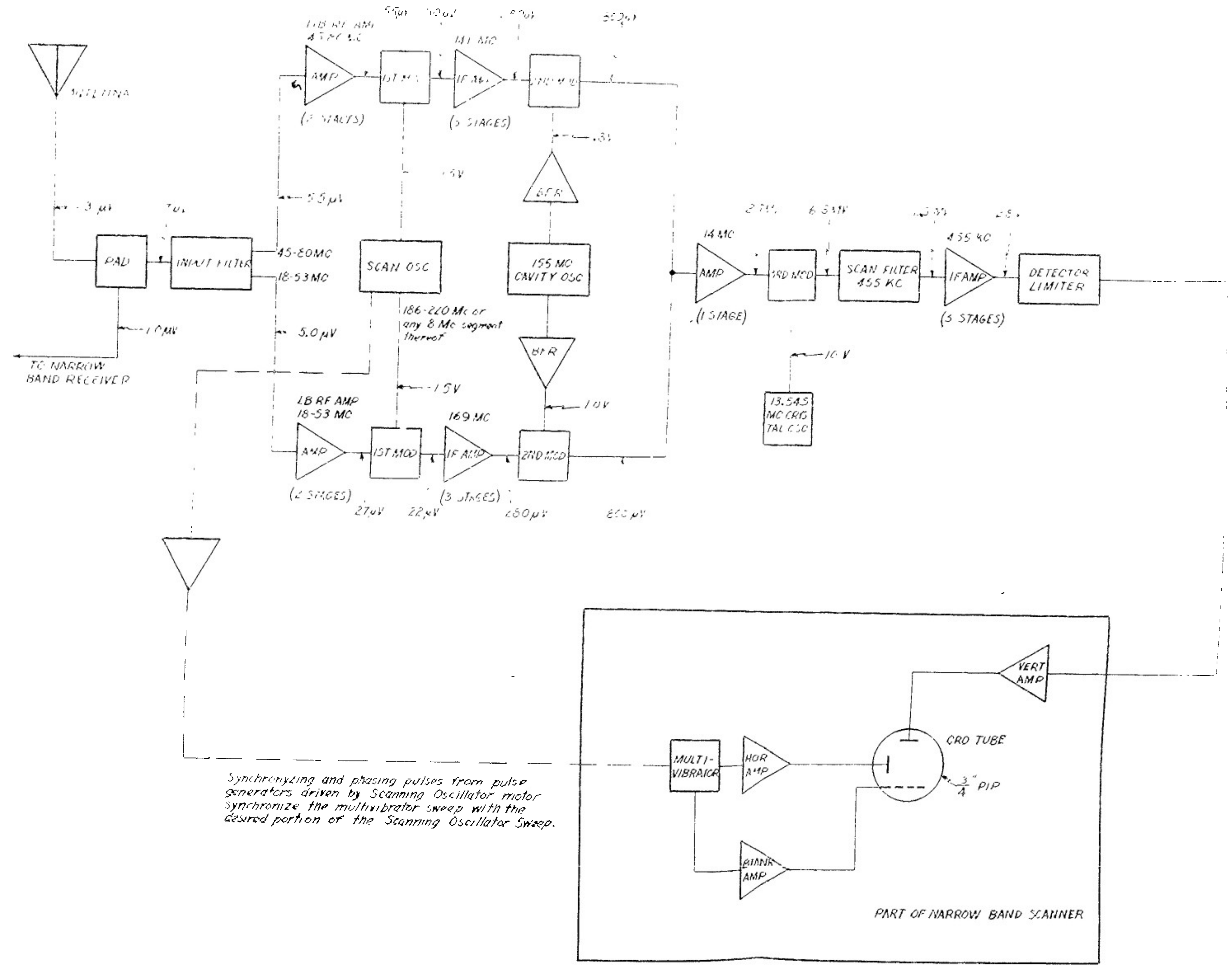

FIG 4

1 4-14-45

SIMPLIFIED BLOCK DIAGRAM OF BROAD BAND SCANNER

SCALE

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ESO-809423

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STOCK SPECIFICATION

SIZE	KIND	SHAPE	TEMPER

ISSUE		DR	TITLE	BELL TELEPHONE LABORATORIES INC
1	4-10-45 ERT	REJ	INPUT FILTER	
		ENG.	DISCRIMINATION CHARACTERISTIC	ES-809424

FIG 5

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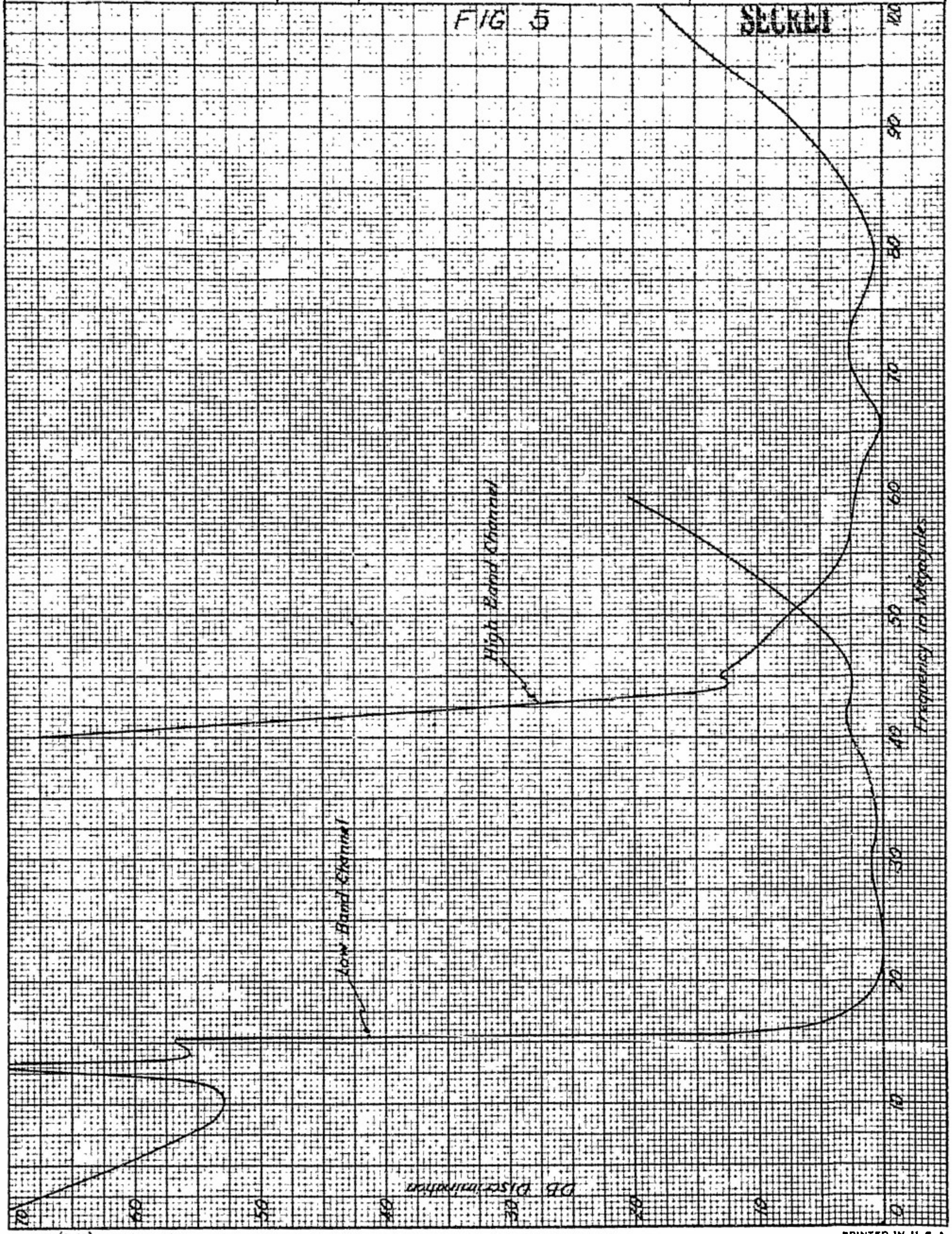
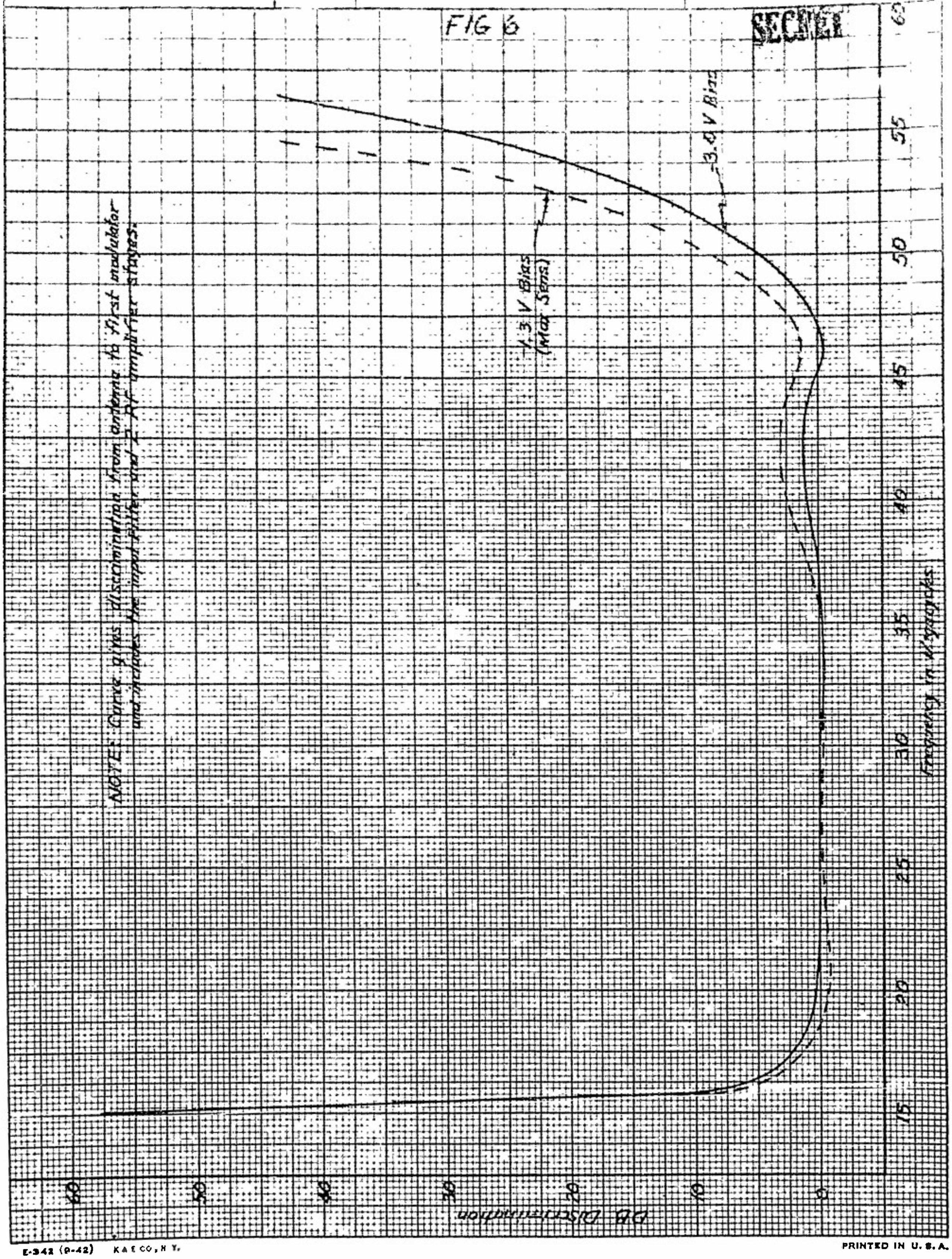


-45 ENI | REV | RF AMPLIFIER DISCRIMINATION CHARACTERISTIC - LOW BAND | C.S. 809425



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ISSUE		DR.	TITLE	BELL TELEPHONE LABORATORIES, INC.
1	4-10-45 ERT	REJ	RF AMPLIFIER DISCRIMINATION	
		ENG.	CHARACTERISTIC - HIGH BAND	ES-809426

FIG 7

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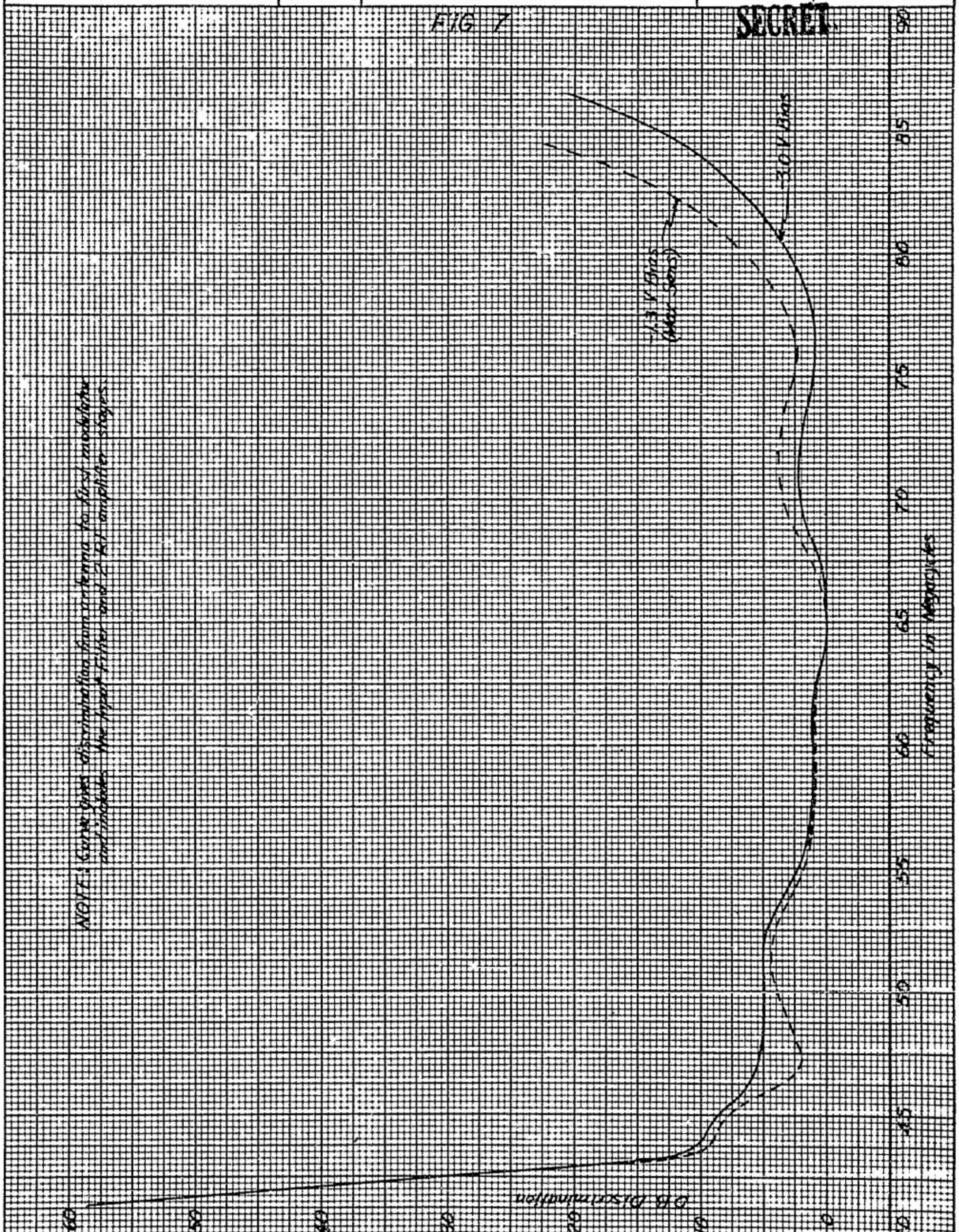
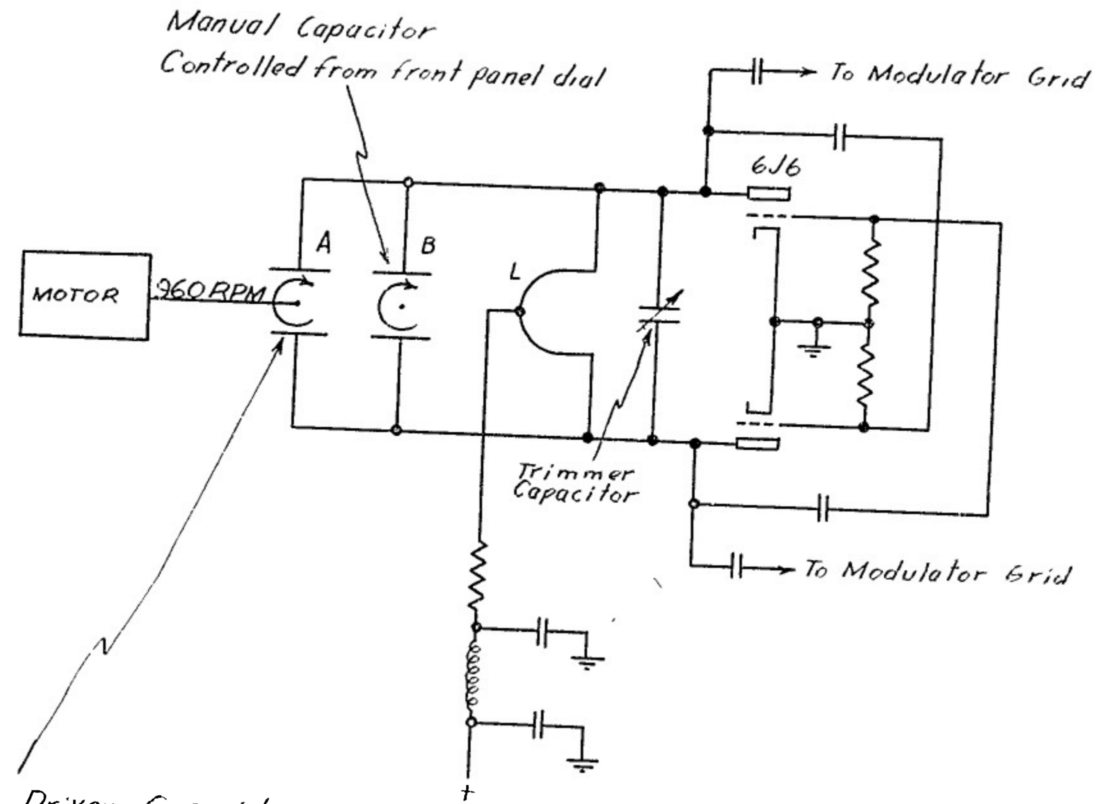


E-342 (9-42) K & E CO., N.Y. PRINTED IN U.S.A.



For wide band sweep the plate separation is close to provide a sweep frequency of 186-222 megacycles with the manual capacitor in the "W" position.

For narrow band sweep the plate separation is wide to provide a frequency delta of at least 8 megacycles, the maximum frequency being determined by the setting of the manual capacitor.

Either of these positions is selected by a toggle action control on front panel.

FIG 8

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ERT REJ

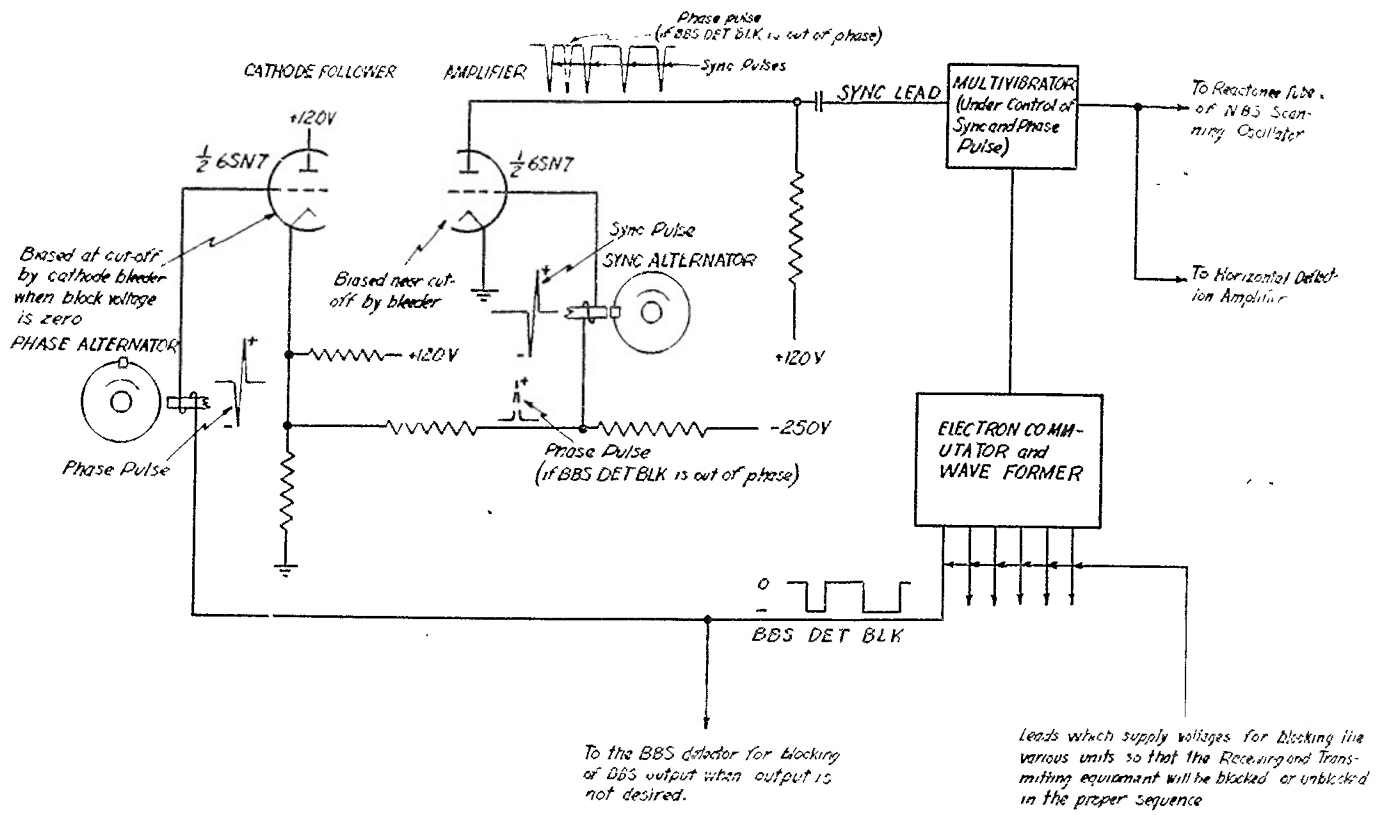
MOTOR DRIVEN SCANNING OSCILLATOR

SCALE

BELL TELEPHONE LABORATORIES, INC. NEW YORK

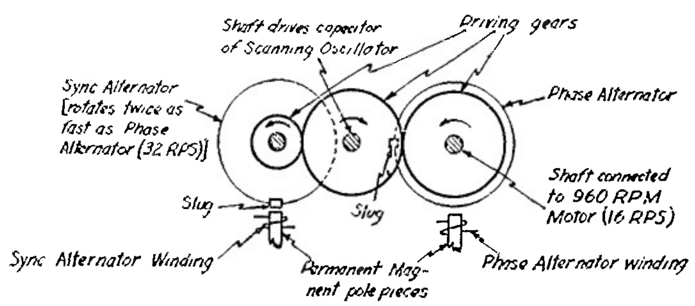
ES- 809433

E-318-E (9-42)



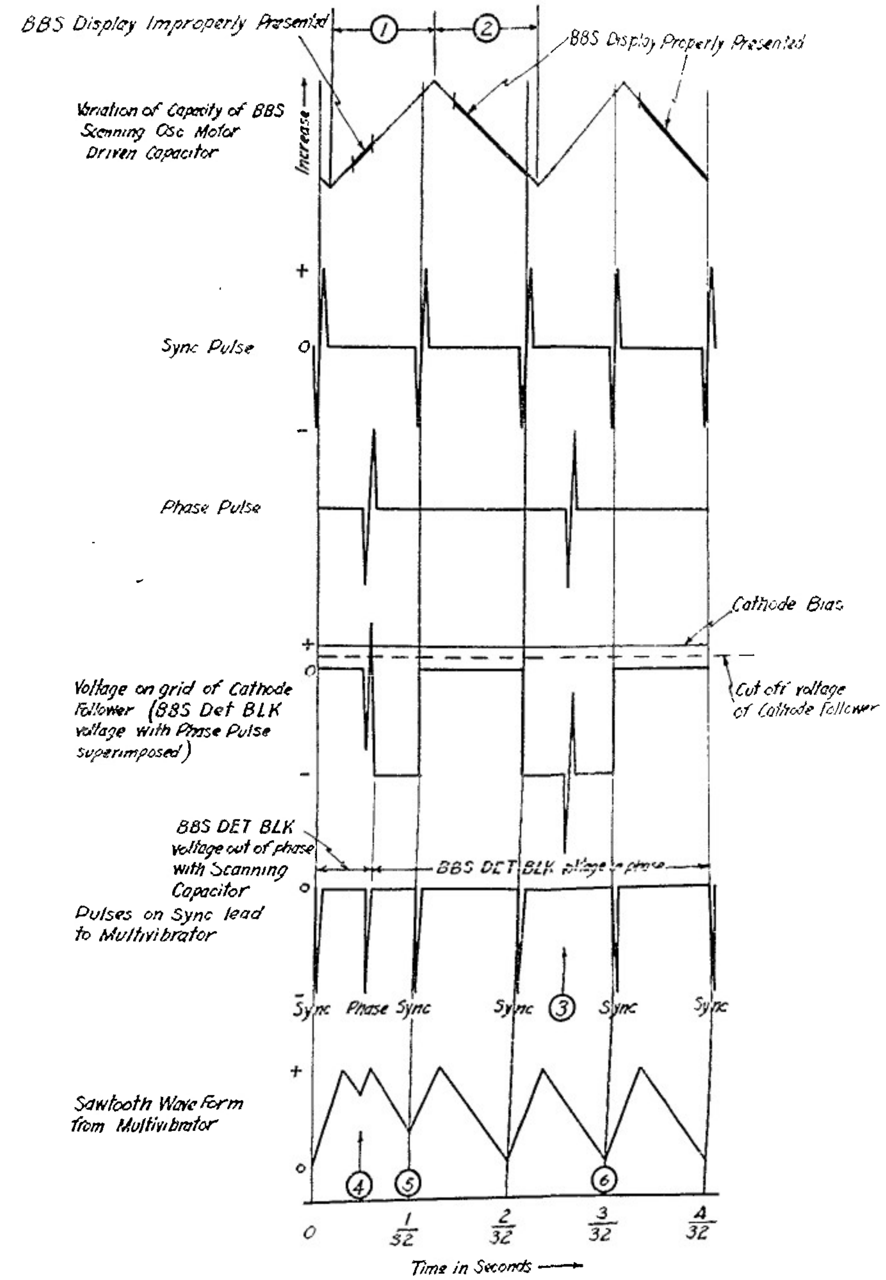
Block Diagram of Phasing and Synchronizing Circuits

FIG B



Mechanical Arrangement of Sync and Phase Alternators Position of Slugs Correspond to Zero Time of Fig C

FIG A



NOTES:
1. Scan Osc frequency decreasing (BBS display not desired, BBS DET BLK should be neg.)
2. Scan Osc frequency increasing (BBS display is desired).
3. Phase pulse is not passed because Cathode Follower is biased too far beyond cut-off by BBS DET BLK voltage.
4. Mult is stepped by Phase pulse and sets Wave Former to block BBS detector output so BBS display is not seen.
5. Mult is stepped by Sync pulse. Operation is now normal.
6. Mult is stepped by Sync pulse and sets Wave Former so BBS display is seen.

WAVE FORMS DURING PHASING

FIG C

FIG 9

DIMENSIONS UP TO AND INCLUDING 72 INCHES EXPRESSED IN INCHES NON LIMITED DIMENSIONS OTHER THAN SIZE OF RAW MATERIAL SHALL

STOCK SPECIFICATION			
SIZE	KIND	SHAPE	TEMPER

ISSUE	
1	4-16-45

SYNCHRONIZING MECHANICAL AND ELECTRONIC SWEEPS

SCALE	
APP'D	ERT
CH	
DR. REJ	ENG

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ESO-809437

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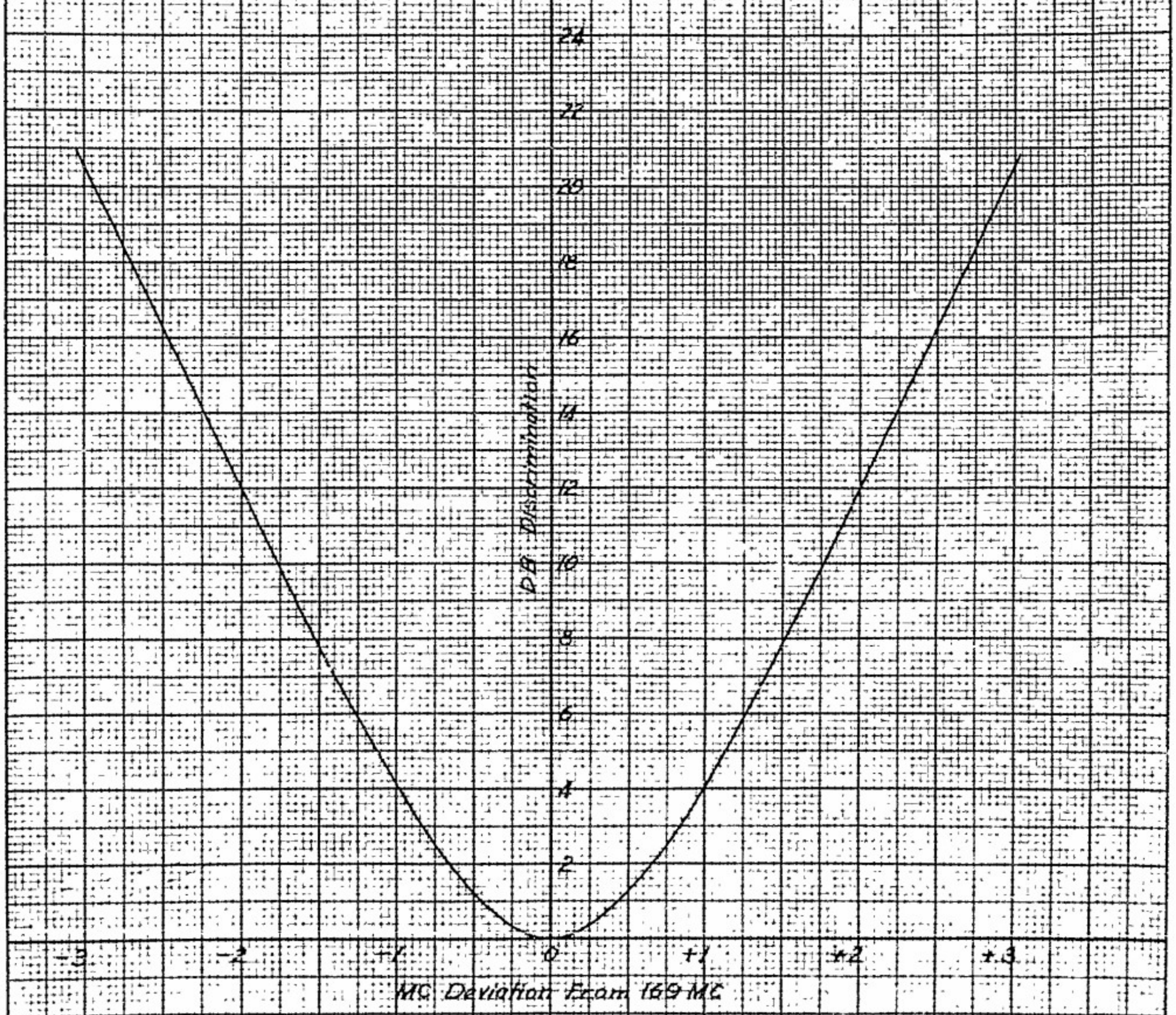
ISSUE	DR.	TITLE	BELL TELEPHONE LABORATORIES INC
1 4-11-45 ERT	REJ ENG	169MC IF AMPLIFIER DISCRIMINATION CHARACTERISTIC	ES-809427

FIG 10

SECRET

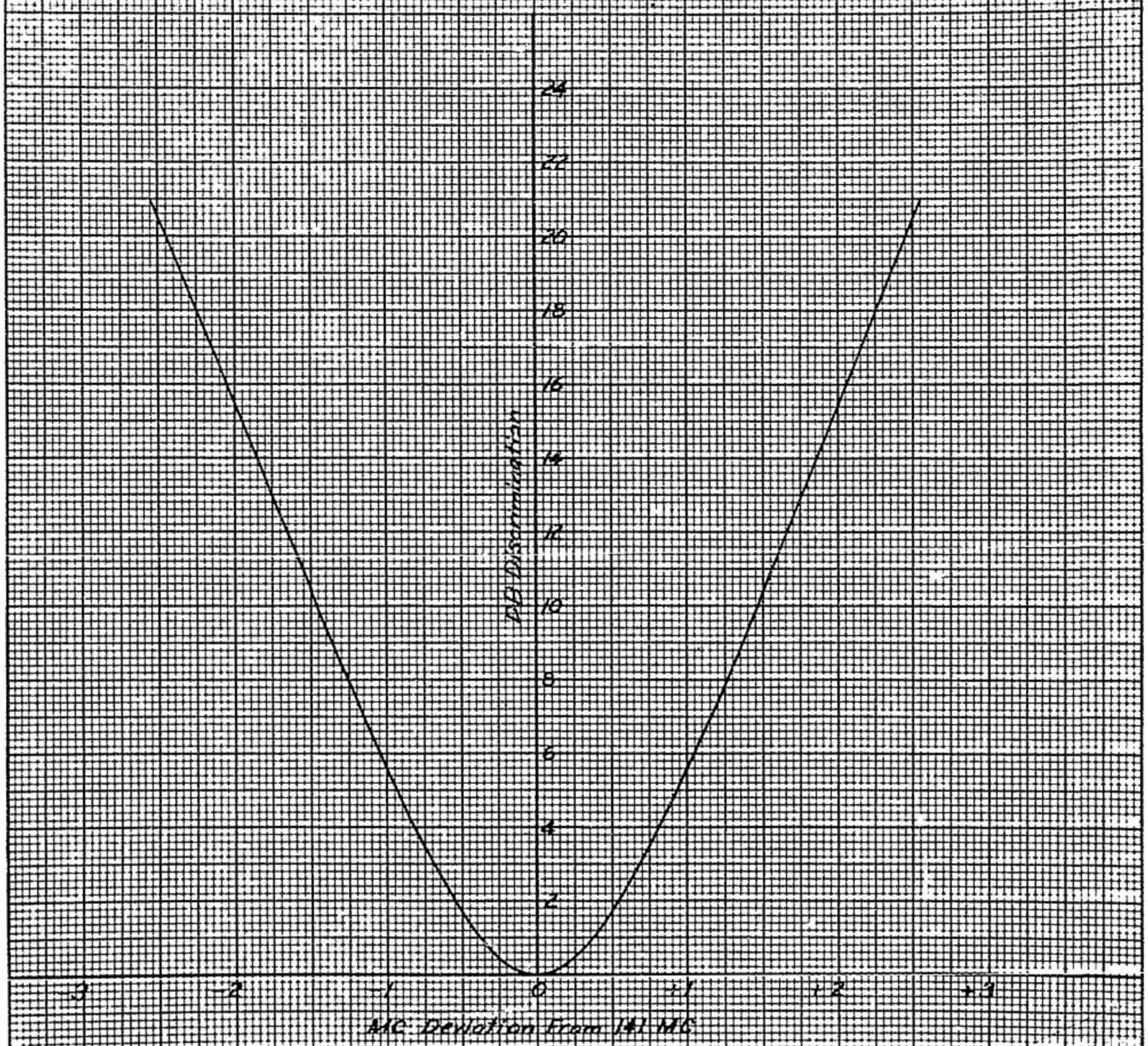


E-342 (9-42)   PRINTED IN U.S.A.

ISSUE		DR.	TITLE	BELL TELEPHONE LABORATORIES, INC.
1	4-11-45 ERT	REJ	141 MC IF AMPLIFIER	ES - 809428
		ENG.	DISCRIMINATION CHARACTERISTIC	

FIG 11

SECRET



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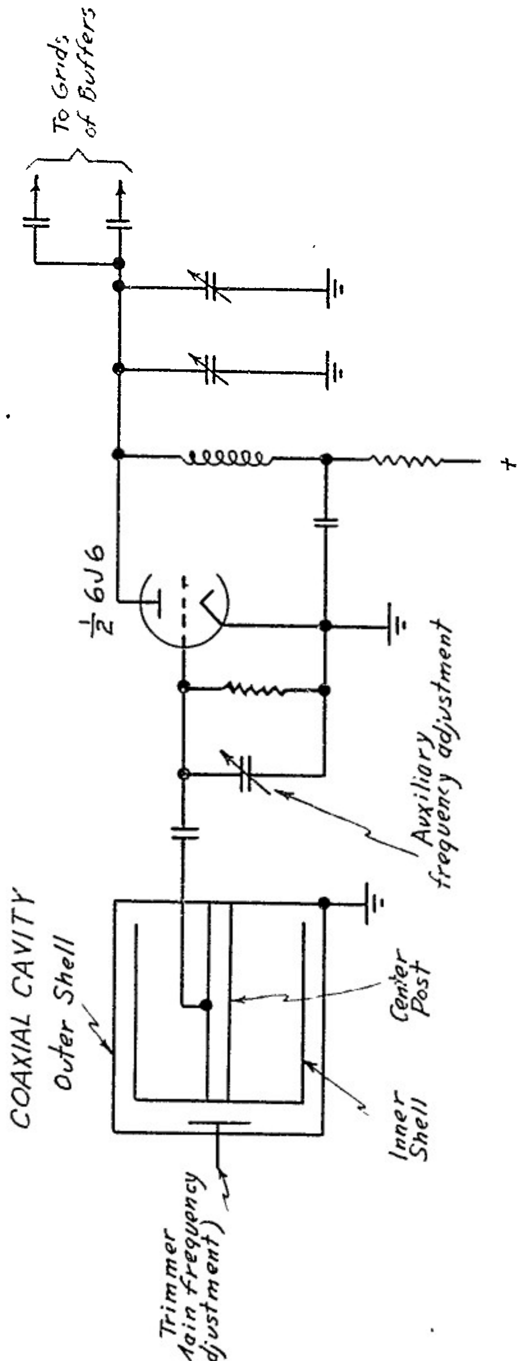

FIG 12

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TITLE

155 MC COAXIAL CAVITY OSCILLATOR SCHEMATIC

SCALE

ISSUE			
1	4-18-45	ERT	REJ

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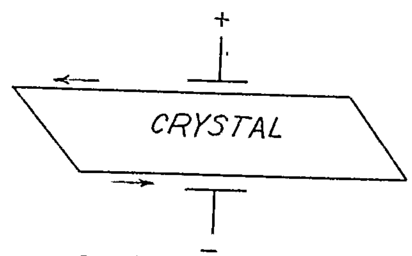
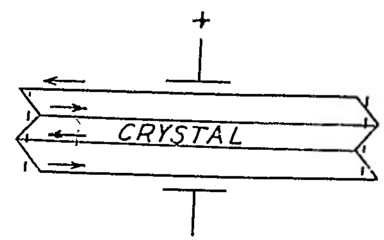
ES-809435

E 3'8-E (9-42)



Crystal operating at fundamental frequency F

FIG A



Crystal operating at frequency of 3F

FIG B

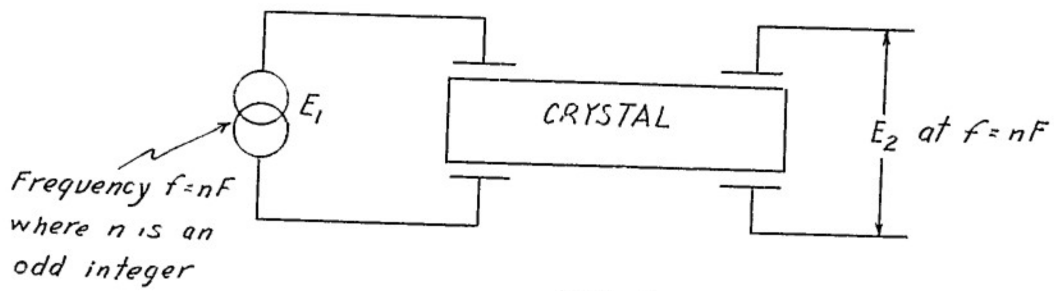


FIG C

FIG 13

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ISSUE	1 4-17-45
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TITLE	LONGITUDINAL MODES OF CRYSTAL VIBRATION (Side views of flat crystal plates)
SCALE	
BELL TELEPHONE LABORATORIES, INC., NEW YORK	
	ES-809439

E-3*8-E (9-42)

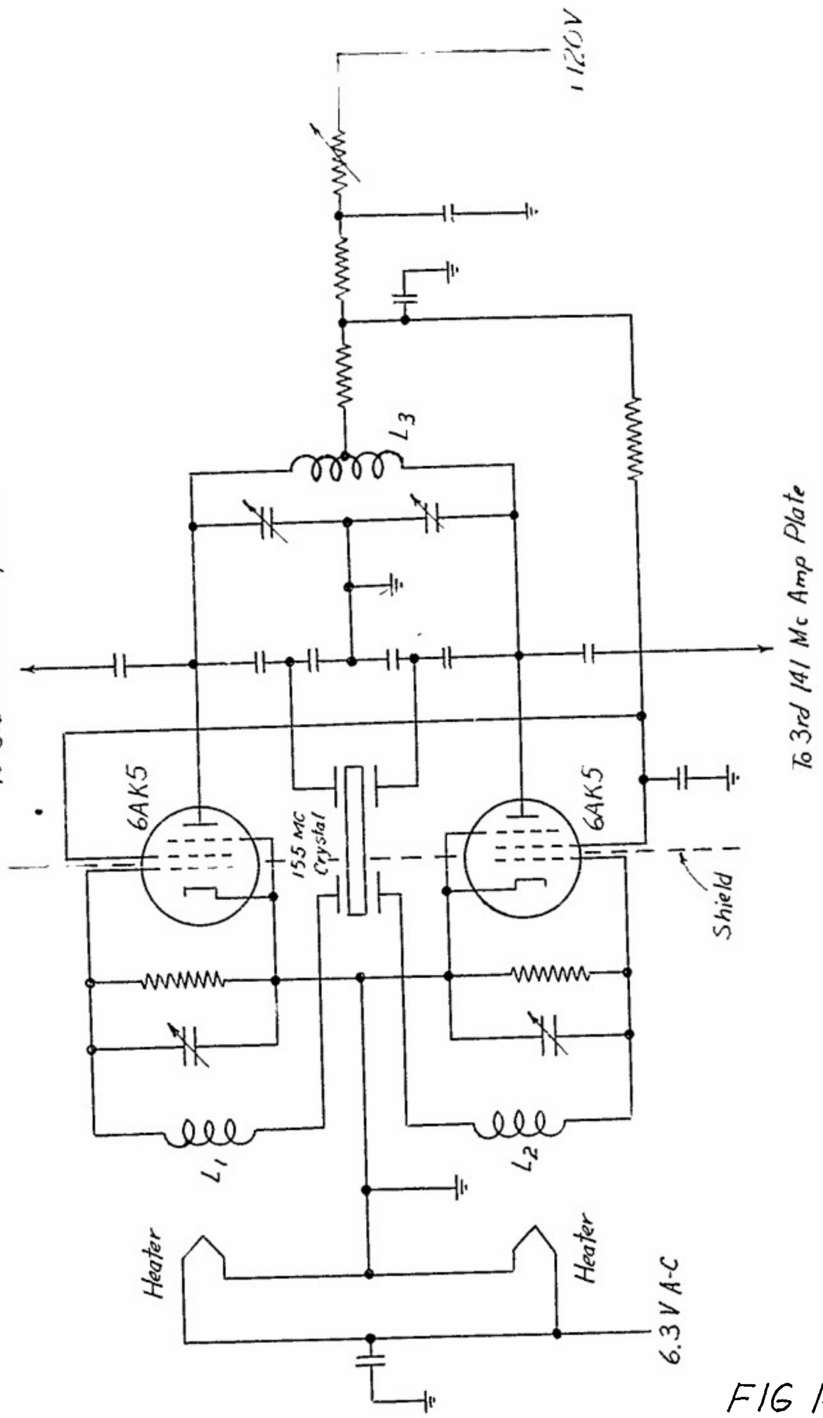

FIG 14

SECRET

TITLE	155 MC CRYSTAL OSCILLATOR
SCALE	
DR REJ	CH
ENG	
APPL EKT	
BELL TELEPHONE LABORATORIES, INC., NEW YORK	
ES-809436	

ISSUE 1 4-5-45

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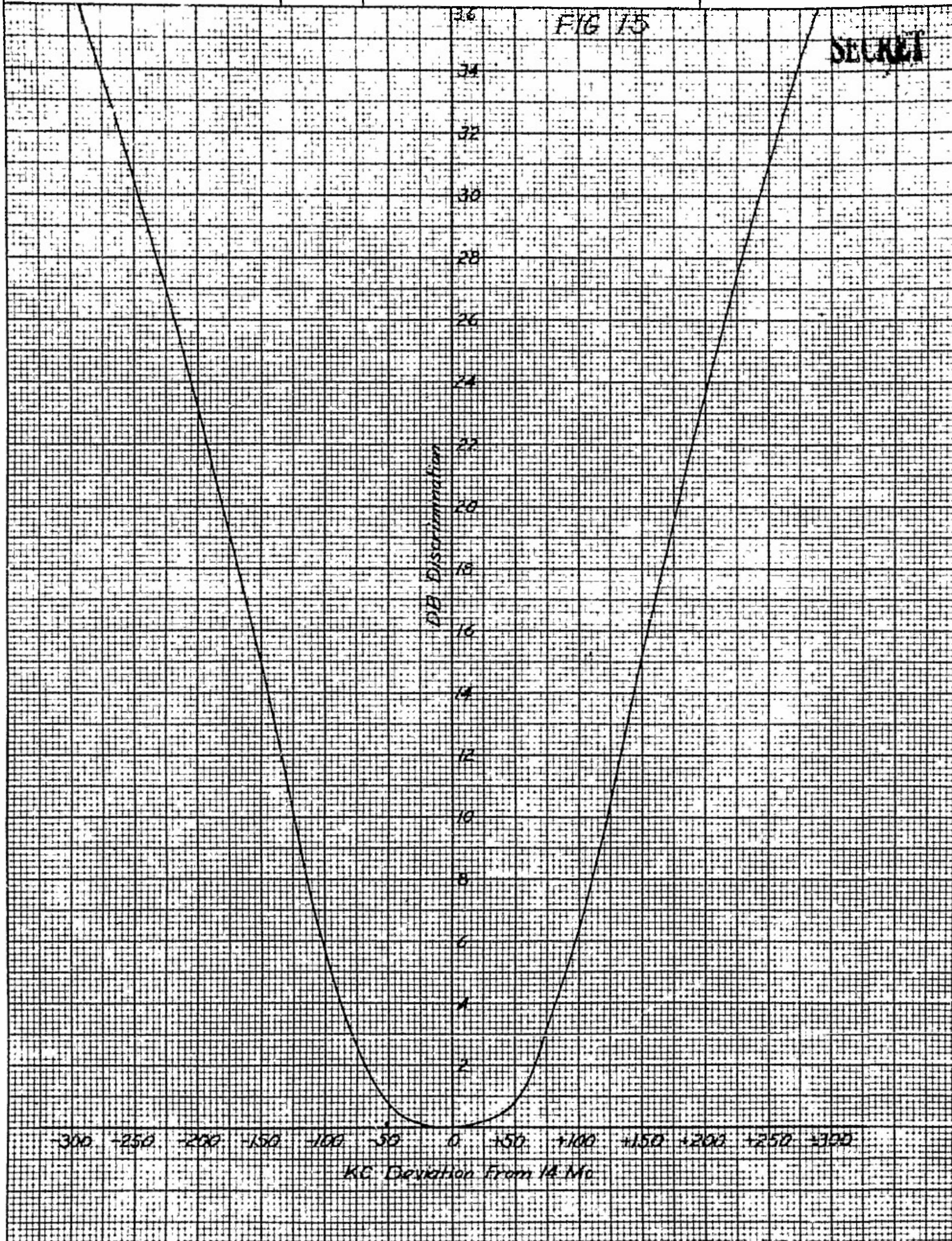
E-318-E(9-42)

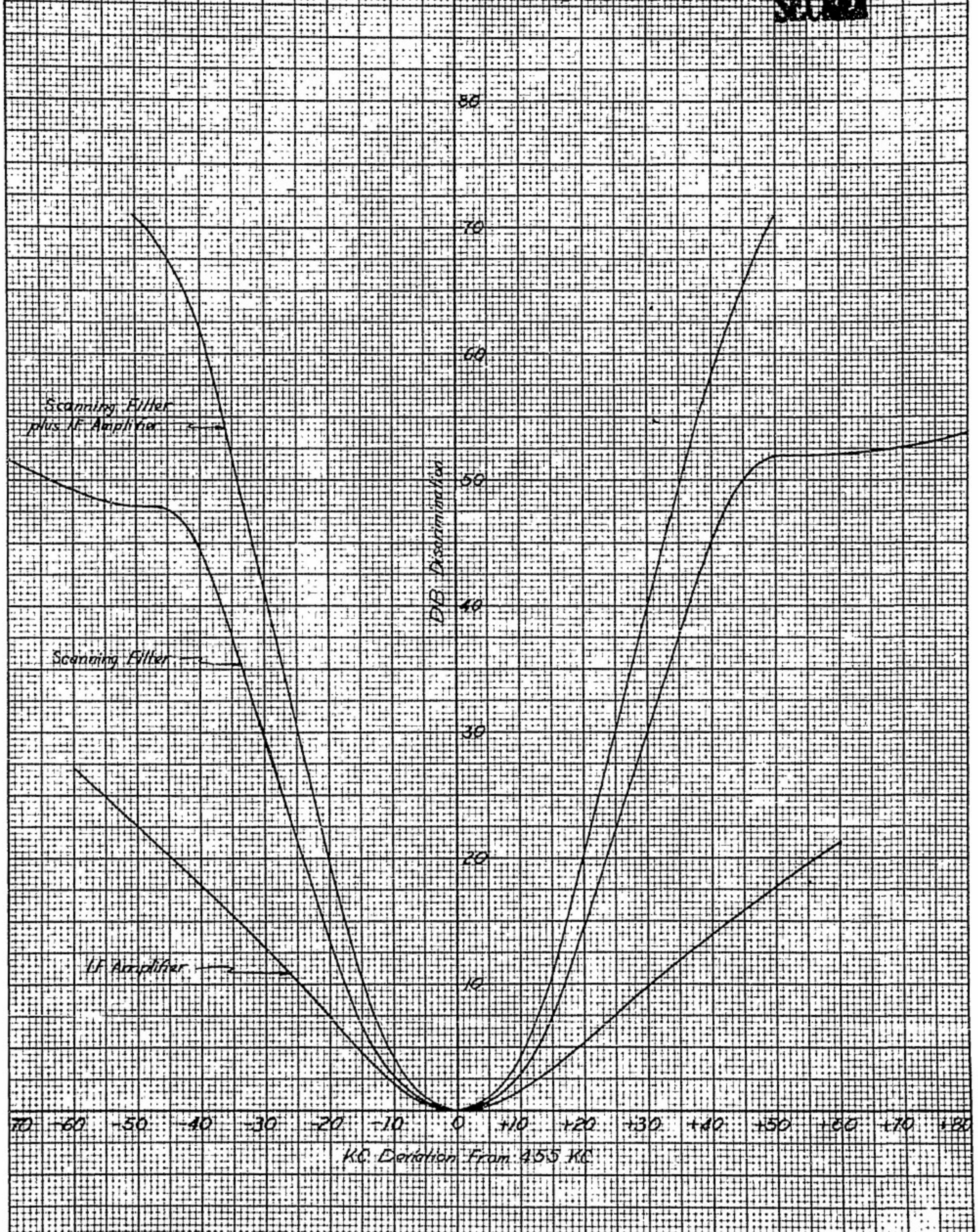
ISSUE	DR.	TITLE	BELL TELEPHONE LABORATORIES, INC
1 4-6-45 ERT	REJ	14 MC IF AMPLIFIER DISCRIMINATION CHARACTERISTIC	ES-809429
	ENG		



ISSUE	DR.	TITLE	BELL TELEPHONE LABORATORIES, INC
1 4-5-45 ERT	REJ ENG.	455 KC IF AMPLIFIER DISCRIMINATION CHARACTERISTICS	ES - 809430

FIG 16

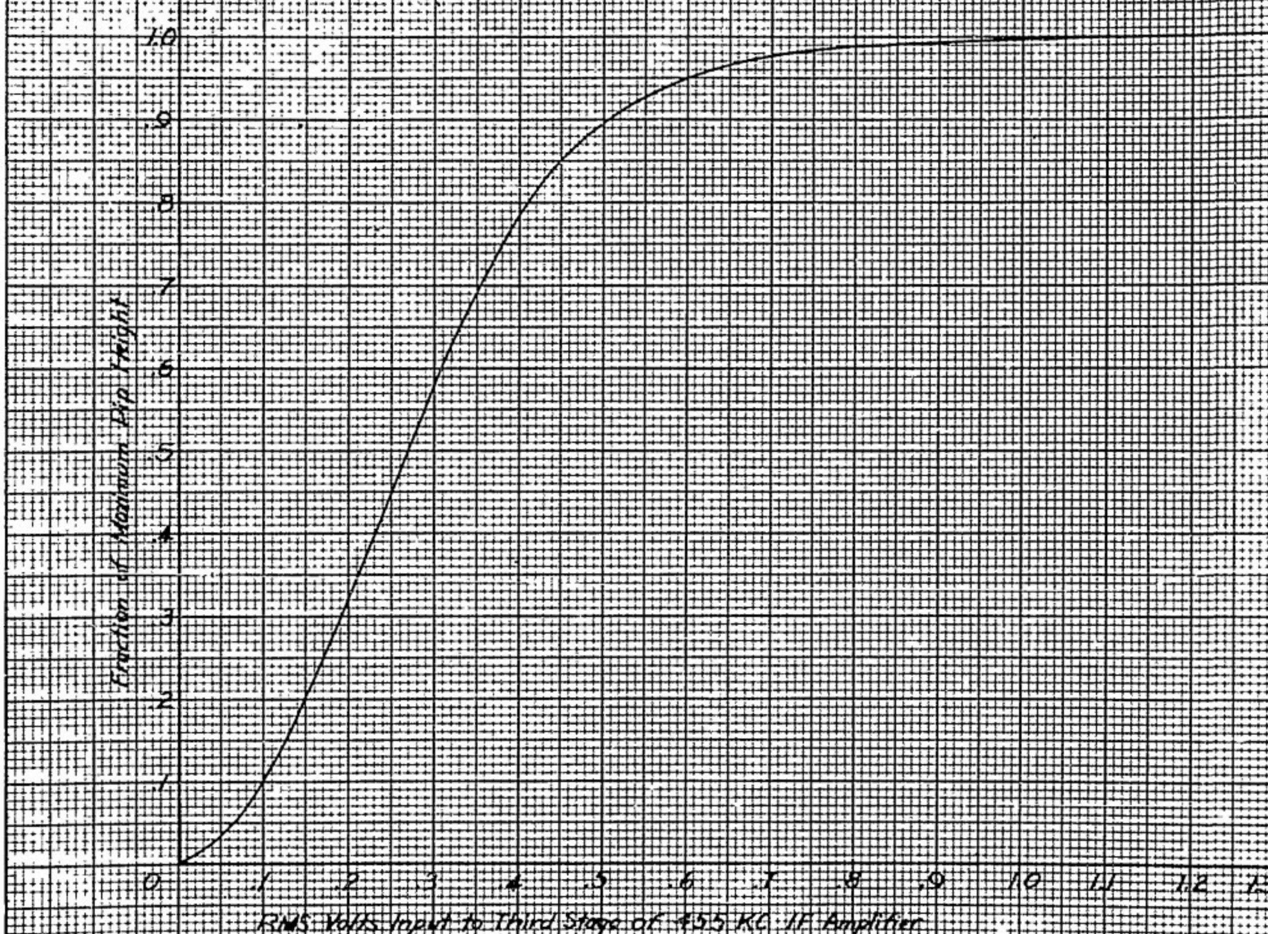
SECRET



ISSUE	DR.	TITLE	BELL TELEPHONE LABORATORIES, INC
1 4-6-45 ERT	REJ ENG.	LIMITING CHARACTERISTIC OF 455KC IF AMPLIFIER AND LIMITER	ES-809432

FIG 17

SECRET



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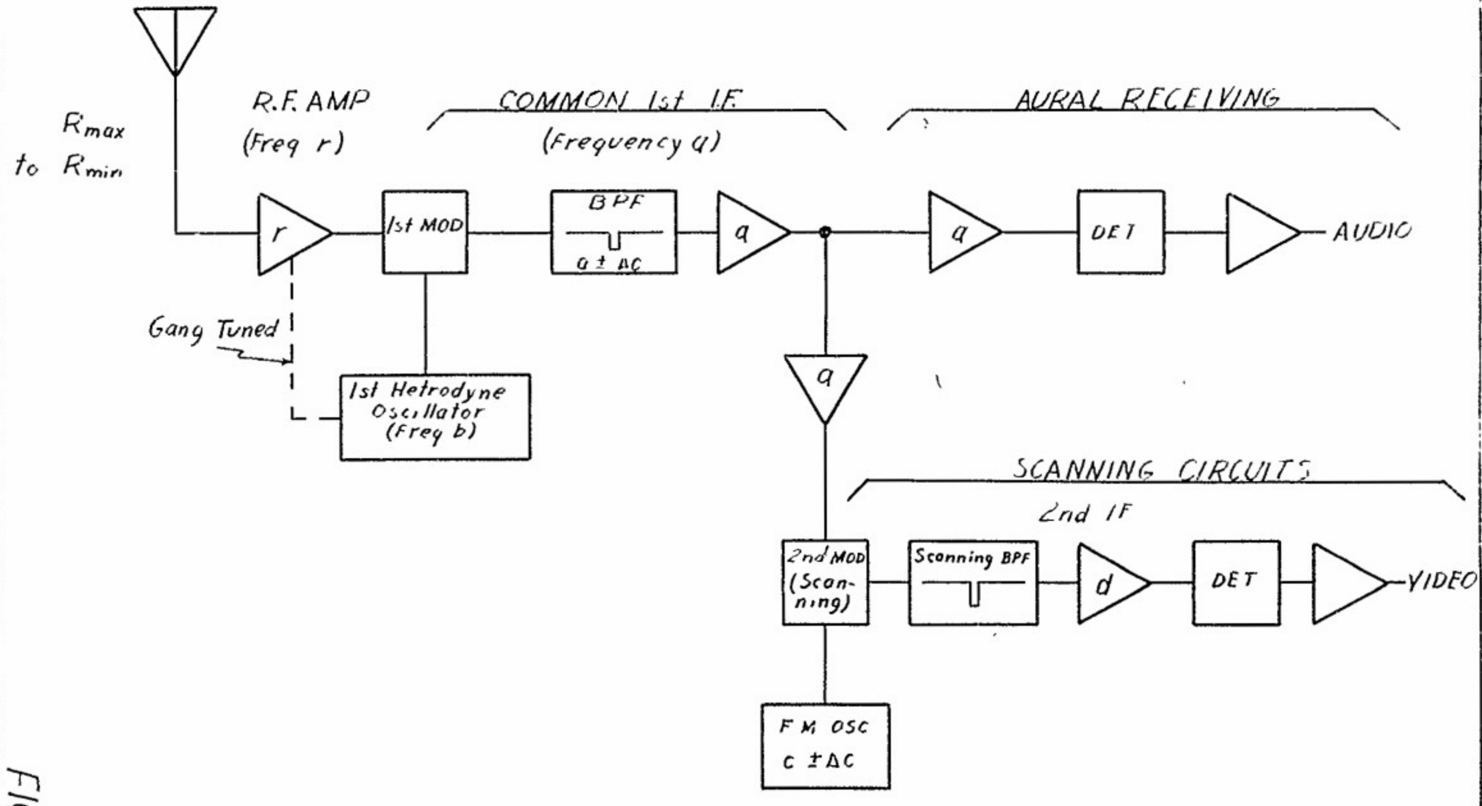

FIG 18

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EKT	REJ

NARROW BAND RECEIVER
Typical Schematic Diagram

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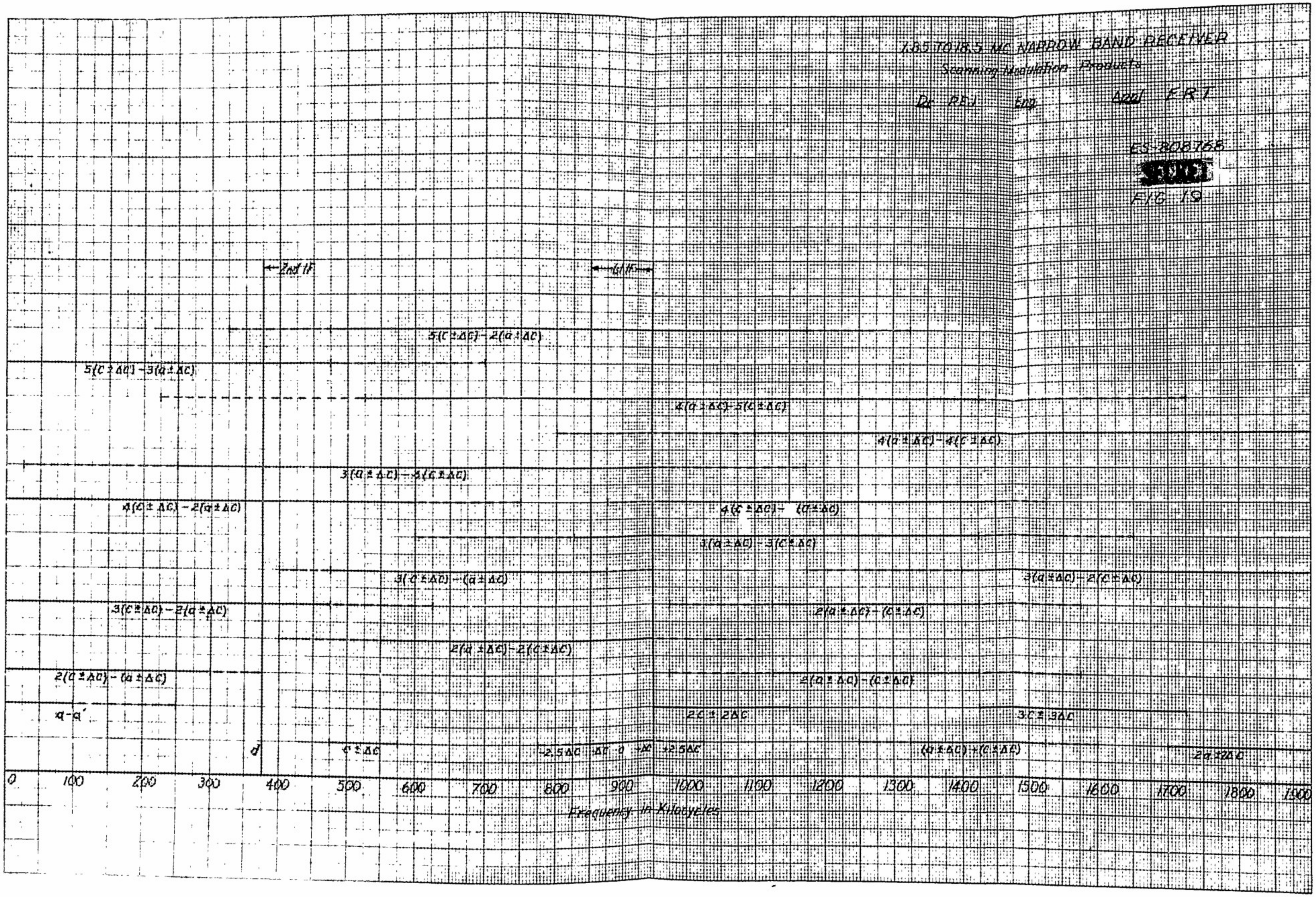
BELL TELEPHONE LABORATORIES INC. NEW YORK

ES-809443

E 318 E (9-42)



1.85 TO 18.5 MC NARROW BAND RECEIVER
Scanning Modulation Products
Dr. REJ
Eng.
Appd. FRT
ES-808768
FIG. 19
2nd IF
1st IF
5(c ± Δc) - 2(a ± Δc)
5(c ± Δc) - 3(a ± Δc)
4(a ± Δc) - 5(c ± Δc)
4(a ± Δc) - 4(c ± Δc)
3(a ± Δc) - 4(c ± Δc)
4(c ± Δc) - 2(a ± Δc)
4(c ± Δc) - (a ± Δc)
3(a ± Δc) - 3(c ± Δc)
3(c ± Δc) - (a ± Δc)
3(a ± Δc) - 2(c ± Δc)
3(c ± Δc) - 2(a ± Δc)
2(a ± Δc) - (c ± Δc)
2(a ± Δc) - 2(c ± Δc)
2(c ± Δc) - (a ± Δc)
2(a ± Δc) - (c ± Δc)
a - a'
2c ± 2Δc
3c ± 3Δc
d
c ± Δc
-2.5Δc -Δc 0 +Δc +2.5Δc
(a ± Δc) + (c ± Δc)
2a ± 2Δc
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900
Frequency in Kilocycles

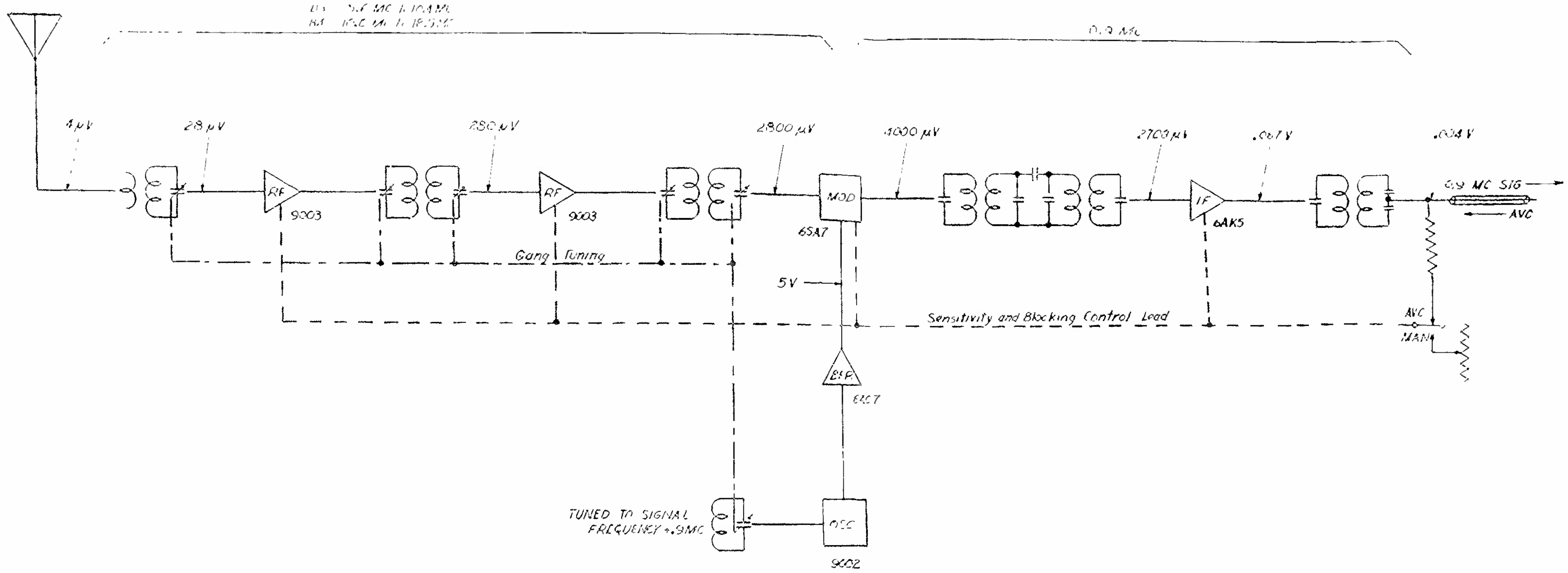


FIG 20

1	4-16-45

1.85 TO 18.5 MC NARROW BAND RECEIVER
RF and Common I.F. Circuits

APPD ERT

DR REJ

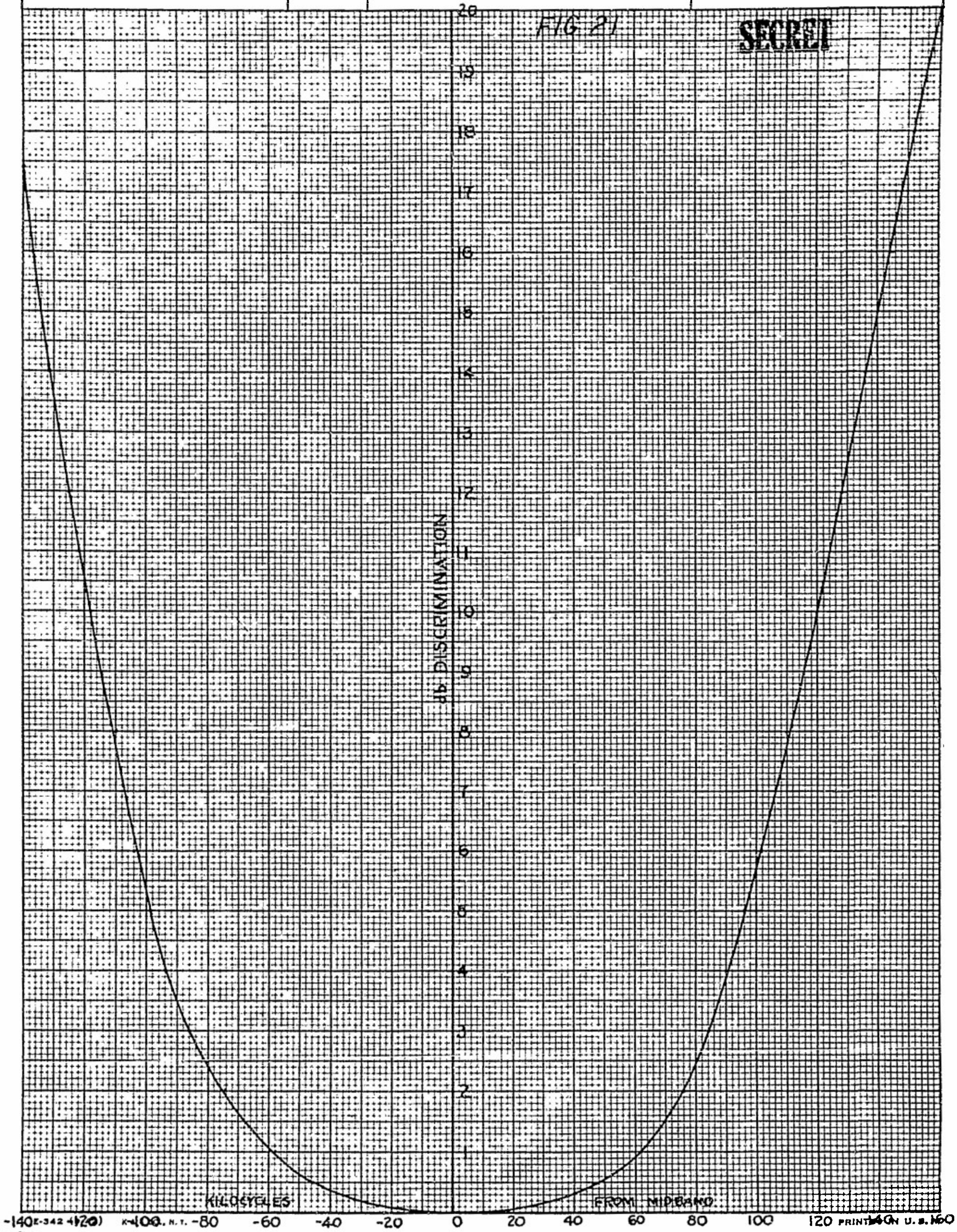
BELL TELEPHONE LABORATORIES INC
NEW YORK

ESO-809444

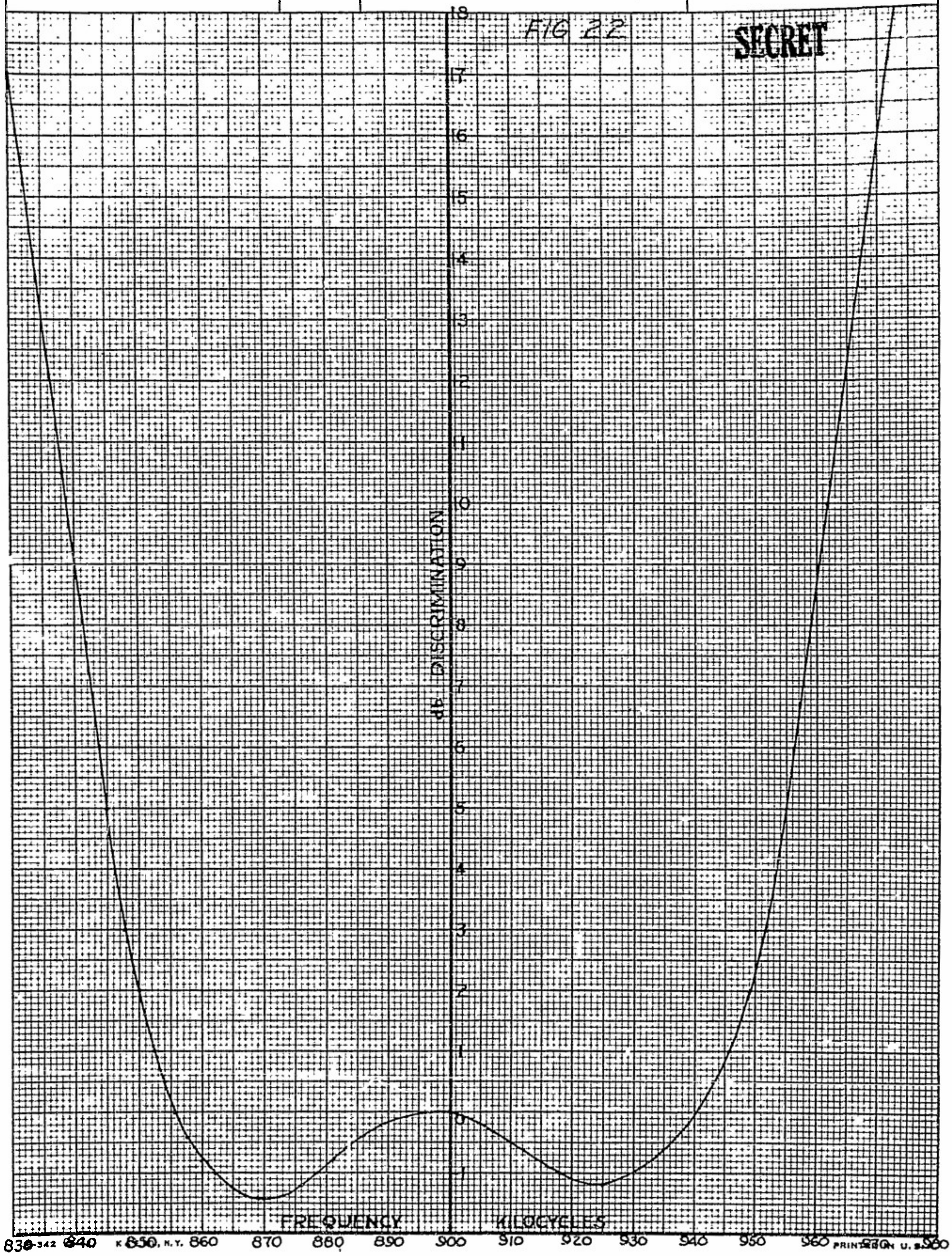
SECRET

STOCK SPECIFICATION

ISSUE	DR.	TITLE	BELL TELEPHONE LABORATORIES, INC
1-4-9-45 ERT	HWE	DISCRIMINATION OF	
	ENG.	RADIO FREQUENCY STAGES, 2 MC	ES-809445



ISSUE 1 4-9-45 ERT	DR. HWE / ENG.	TITLE 0.9 MC IF AMPLIFIER DISCRIMINATION CHARACTERISTIC	BELL TELEPHONE LABORATORIES, INC ES-809446



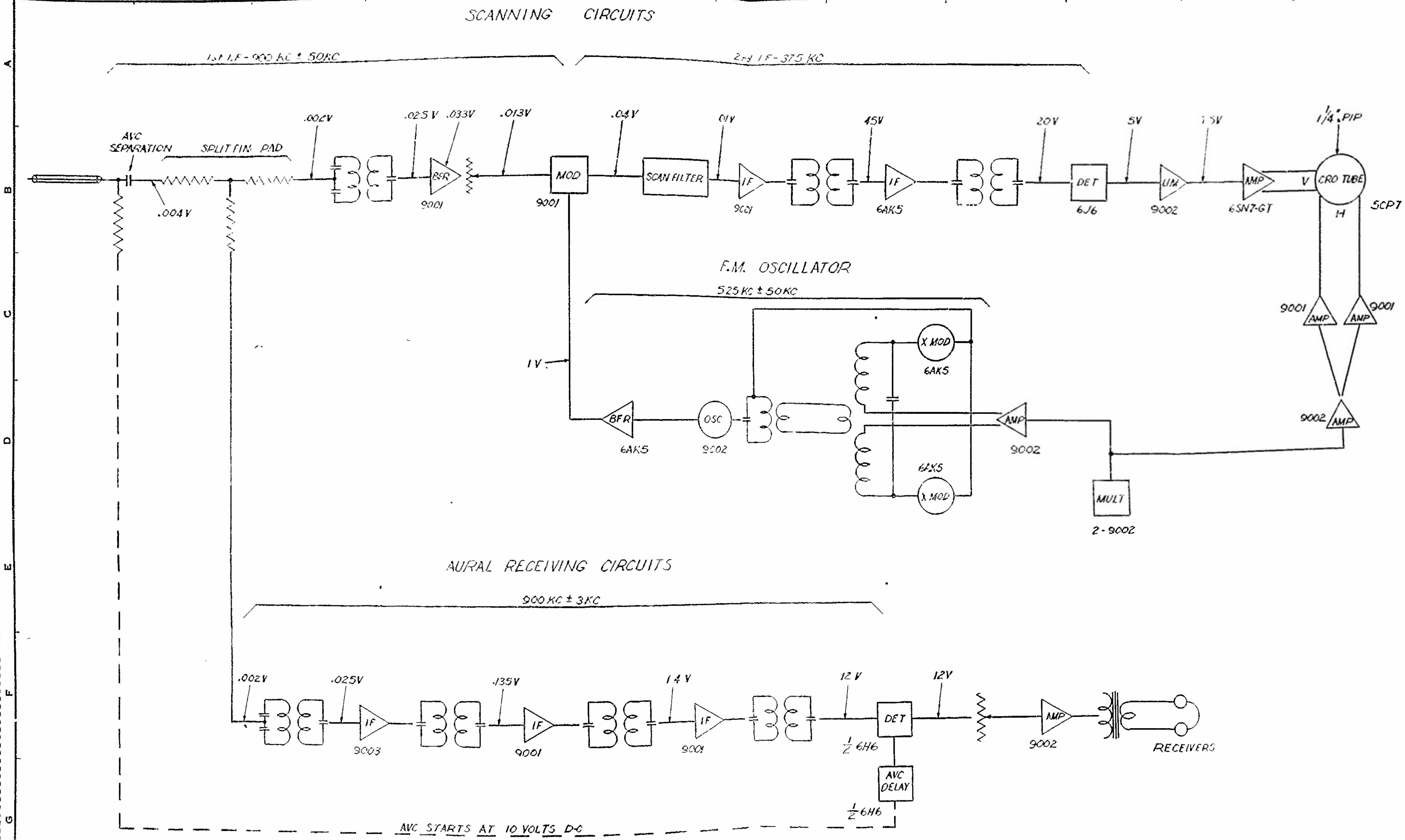


FIG 23

ISSUE 1 4-16-45

1.85 TO 18.5 MC NARROW BAND RECEIVER
Scanning and Aural Receiving Circuits

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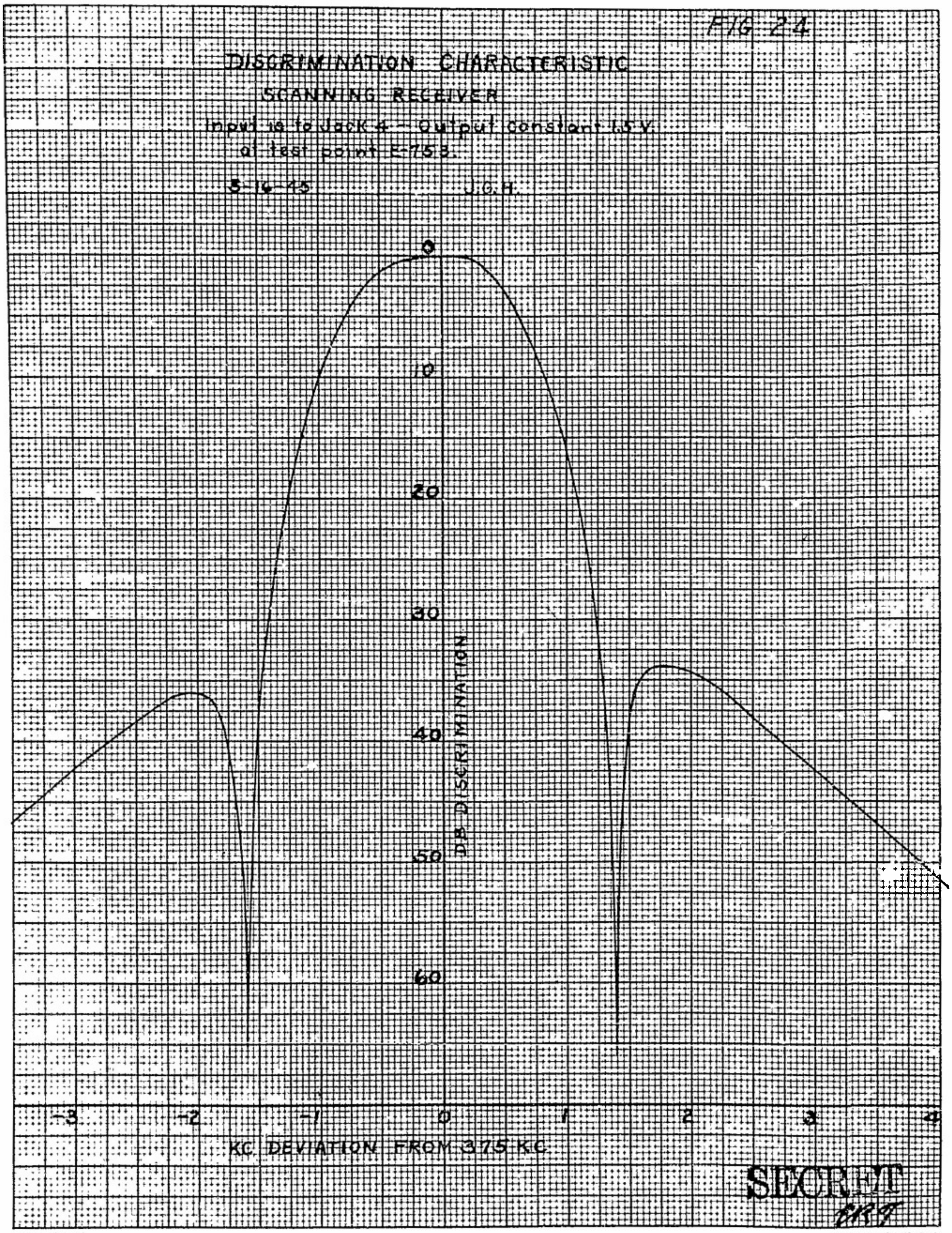

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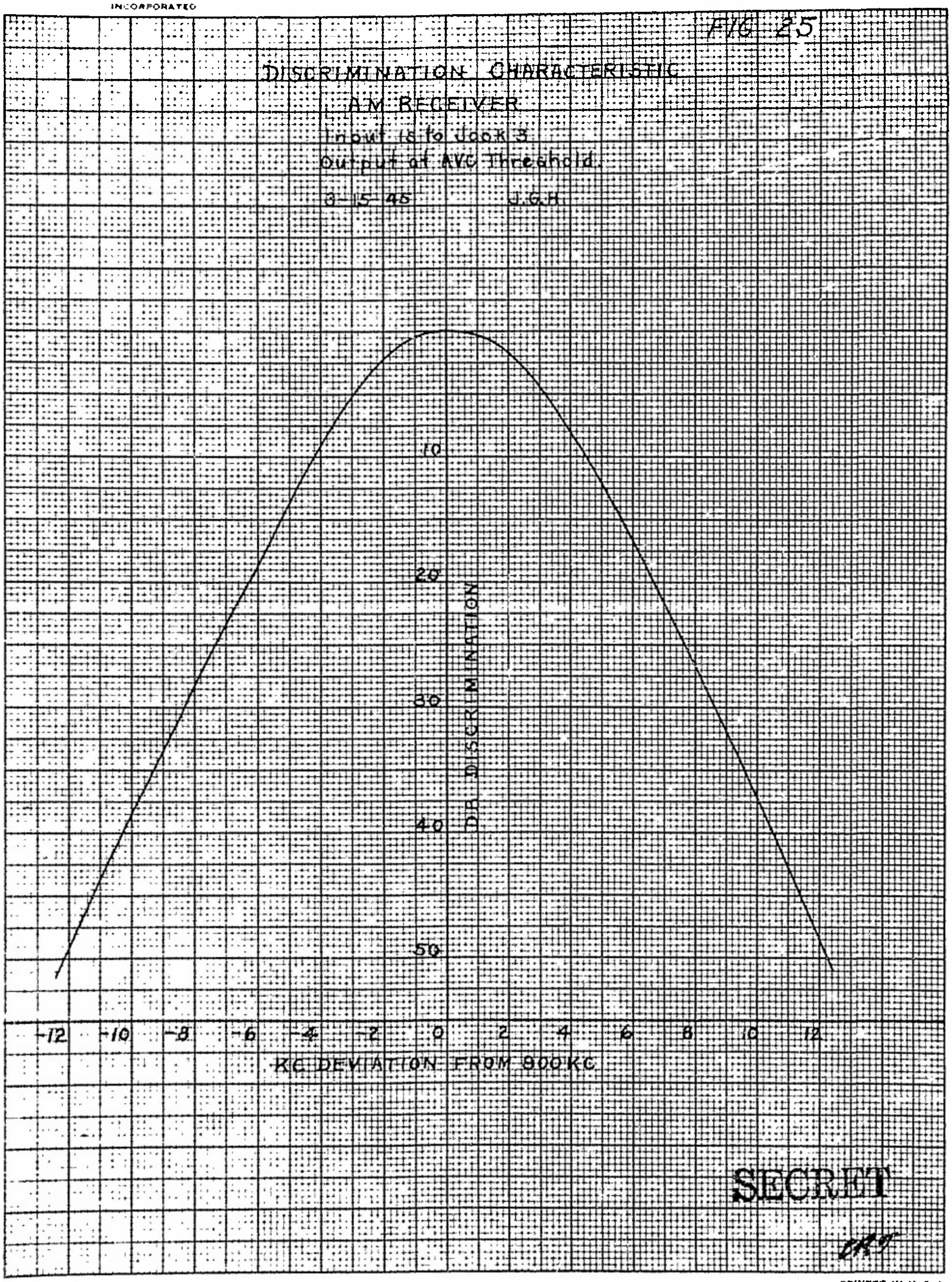

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